The Prevalence and Productivity Effects of Close Friendship in Academic Science

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The Prevalence and Productivity Effects of Friendship in Academic Science

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Friendship and its virtues are not merely private: they are public, even political, for a civic order, a 'city', is above all a network of friends (Bellah et al 2007, p. 116).

This dissertation is dedicated to my daughter and each and every one of my closest friends – all those with whom we share various aspects of our *Vita Activa*.

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LIST OF ABREVIATIONS

ANOVA	Analysis of variance
NBR	Negative binomial regression
NSF	National Science Foundation
NSB	National Science Board
OLS	Ordinary least squares
S&T	Science and technology

SUMMARY

This dissertation examines the prevalence of friendship and its effects on productivity in academic science from the perspective of networked social capital. It seeks to understand what friendship is in the context of the professional environment, what distinguishes it from other professional relationships, especially collaborative, and how it affects the function and the outcomes of science. The study was motivated by the increased emphasis of collaboration as a means of fostering research competitiveness and advancement in academic science and engineering careers. These goals are reflected in a broad range of policies on various levels, including the requirements of funding agencies. Scientists are encouraged to collaborate, particularly across institutional and disciplinary boundaries, and institutions are encouraged to establish more inclusive collaborative environments in which individual scientists and engineers can achieve their highest potential and productivity.

A substantial body of knowledge suggests that at the heart of research competitiveness is scientific excellence, and collaboration is the primary means of attaining excellence. However, the analysis of competitiveness is typically conducted at the institutional level. A smaller body of knowledge addresses the role and the importance of networks of personal relationships and the properties of these relationships in the execution of scientific work that contributes to this body of knowledge. The importance of friendship in the context of academic science has often been implied and anecdotal, but it has not been elucidated or empirically tested. This dissertation seeks to address this gap and models friendship as a building block of the social capital of a scientist and a catalyst of publication productivity. The unit of analysis in the model is the individual. Theoretically, the dissertation conceptualizes friendship as one aspect of a collaborative relationship and thus an important determinant of a scientist's social capability of pool relevant resources for the purposes of productivity. It hypothesizes that professional and personal roles form an integrative relationship within collaborative ties and that such complementarity benefits individual goal attainment, specifically with regard to publication productivity.

The results of the study show that friendship has a strong positive effect on an individual's publication productivity, which is comparable to the effect of collaboration across organizational boundaries. The results also show that while friendship is fairly prevalent in collaborative relationships, some groups of scientists are more likely to have friends among their closest collaborators than other groups; that friendships differ from other collaborative relationships in that they more often form between individuals of the same status, provide a greater variety of productivity-relevant resources such as knowledge, advice, endorsements of one's reputation, and introductions to potential collaborators; and that friendship facilitates the mobilization of these resources from personal collaborative networks for productivity purposes. As a result of these findings, several theoretical and policy implications will be discussed.

1. INTRODUCTION

Of all informal relationships between individuals, *friendship* is omnipresent in human life (O'Connor 1992). Metaphorically speaking, friendship is seen as a form of "social glue" (Pahl 2000, Spencer and Pahl 2006). In fact, recent work has recognized friendship as an "increasingly important architectural dimension" of an organization (Dickie 2009, p 128). Some suggest that friendship is the heart of social organizations (Kaufman 1992), an organizing principle, and the core of the ethos of the organization (Grey and Sturdy 2007). This emerging body of literature has linked friendship to a range of individual and organizational outcomes, including work satisfaction, commitment, productivity, and other factors (Berman et al. 2002, Crabtree and Space 2004, Farrell 2001, Nielsen et al. 2000). A gap, however, exists in our understanding of this personal relationship in the social structure of science, raising the following question: Does friendship among scientists exist within the professional environment? If so, what is friendship? What distinguishes it from other professional relationships? And how does it affect the function and outcomes of science? To address these questions this dissertation examines close friendships between academic scientists and their closest collaborators. As a caveat, this research is limited to self-identified "close friends." Some limitations to the operationalization (addressed later in this dissertation) mean that this work is exploratory. For example, variation in types of friends, as well as cultural interpretations of "friendship" are not accounted for here. Nonetheless, this research offers some initial insight to the role that friendship may play in the function of science.

Research pertaining to the social structure of science tends to focus primarily on the professional, both formal and informal, aspects of these relationships: hierarchy, authority, autonomy, power, and relative expertise (Bourdieu 1991, Latour 1987, Merton 1973, and Polanyi 2000, among others). These studies have primarily focused on how such factors affect the outcomes of scientific work and other factors central to the careers of scientists. Nevertheless, the complex social structure of science is self-organized (Melin 2000, Polanyi 2000, Wagner and Leydesdorf 2005). According to Polanyi (2000), scientists belong to professional groups in which their competencies overlap to some extent. Since these groups also overlap, science, in its entirety, is comprised of chains and networks of overlapping "neighborhoods." These neighborhoods, or networks, are a locus of scientific opinion, and each link in these networks establishes agreement about the valuation of scientific merit. The standards of scientific merit are institutionalized and passed on from generation to generation of individual scientists in much the same way as moral, legal, or artistic traditions are passed through generations. Self-organization is also manifested in scientific "invisible colleges" and the epistemic and personal communities of scientists (Crane 1972, Davenport and Hall 2002, Adler and Haas 1992, Kadushin 2012, Polanyi 2000, Leydesdorff and Wagner 2008). Within the context of science, work is distributed among individuals across organizations in which formal and informal organizational structures co-evolve in complex ways. On a personal level, academic spousal relationships are also not uncommon (Fox 2005, Pycior et al 1996), revealing an intersection of professional and personal lives. On a professional level, scientists typically spend periods of several years in the same organization, further solidifying their relationships in repeated interactions over prolonged periods the time (Dietz 2000, Murray 2004). Within this context, informal and more personal relationships that are not fully understood develop. Legal protection against harassment and favoritism, coupled with an ideology of political correctness, has seemingly pushed personal relationships out of the workplace. However, individuals naturally develop important informal ties that are deeply imbedded in relationships (Kadushin 2012). Thus, the workplace remains a social environment in which individuals interact in a range of ways and, by definition, develop ties and relationships with one another. The science workplace is no exception.

In the context of science, faculty engage in parallel departmental, pedagogical, and other activities, expanding their professional relationships and community, often working with colleagues over a number of years (Bozeman et al.2001, Murray and Graham 2007). Scientists build their personal networks as they move from institution to institution and from project to project (Murray 2004), suggesting that even when they move on, they remain a part of their personal professional communities and organizations, of which they may be a part for their entire professional lives (Dietz et al. 2000, Bozeman et al. 2001, Murray and Graham 2007). Furthermore, science is an increasingly collaborative and distributed endeavor in which scientists work in laboratories, on research teams, and in other groups (Barabasi 2005, Hinds and McGrath 2006, Jones et al. 2008, NSB 2011, Wuchty et al. 2007). Thus, professional and collaborative relationships span institutions, disciplines, and geographic boundaries (Cummings and Kiesler 2005, 2007, Hinds and Kiesler 2002). Through these repeated and long-standing professional interactions, personal relationships are likely to develop; that is, faculty members often become friends with one another and expand their professional interaction to other realms.

Identifying the presence of these personal relationships, including friendships, may be of interest from an intellectual perspective, but studies suggest that they may also have important implications. Most importantly, the nature of social relationships and their level of involvement may have implications for the productivity of scientists. The philosophical literature treats friendship as a form of love, which implies special concerns about and responses to the characteristics of others, such as goodness (Helm 2009). The sociological and anthropological literature defines friendship as a voluntary relationship between autonomous individuals characterized by self-disclosure, affection, acceptance, assistance, ego-reinforcement, emphatic understanding, loyalty, and compatibility (Grey and Sturdy 2007, O'Connor 1992, Parker and de Vries 1993). Features that make friendship distinct from other work relationships are its spontaneity, voluntary nature, and inherent flexibility; friendship is primarily spontaneous and flexible while other workplace relationships are primarily instrumental and rational (Grey and Sturdy 2007, Halpern 1994). Friendship is personal and implies the valuation of a friend for his or her own sake (Helm 2009, 2010, Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008). It also is flexible and implies capacity to accommodate differences (Anderson 2001, Blatterer 2010, Conradson and Lathan 2005, Hruschka 2010, Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008, Lazarsfeld and Merton 1954). These distinctions, however, are conceptual, and therefore do not necessarily reflect the richness of intertwined professional, social, and personal relationships. Friendship typically involves an added level of personal trust (Anderson 2000, Kaufman 1992, Parker and de Vries 1993), which is an aspect of a relationship, a willingness of one party to be vulnerable to another party (Mayer et al. 1995, Schoorman et al. 2007). It is closely related not only to the personal history of a relationship (McGrath et al. 2003, Lewicki et al. 1998, 2006), scientists' knowledge of one another's work, but also to the outcomes of their work and possibly the productivity (Kraut et al. 1987-88, Shrum et al. 2007). Importantly, friendship may affect both the antecedents of trust—the propensity to trust one party and perceived trustworthiness of another (Mayer et al. 1995, Schoorman et al. 2007). Some have argued that the informal structures that emerge from friendship are the primary locus of shared values and attitudes, and therefore, the locus of the formation of scientific and political opinions (Lazarsfeld and Merton 1954, Gibbons 2004, Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008). In science, sustained collaborations, including friendships, may form around shared values, a passion for science, and other substantive and professional interests and expertise (Isaacson 2008, Lazarsfeld and Thielens 1977, Watson 1968, Pycior et al. 1996). What defines friendship, however, is the intense personal aspect of the relationship that may allow the exchange of various resources that differ from those exchanged in strictly professional relationships (Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008, Uzzi 1998). More importantly, these academic friendships may result in new collaborations and entrepreneurial partnerships (Beaver 2001, Francis and Sandberg, 2000, Katz and Martin 1997, Meyer 2003) and facilitate knowledge transfer between organizations with different norms, such as between university and industry partners (Brennenraedts et al. 2006), suggesting an important nuance and added value to relationships that extend beyond the professional interaction to friendship.

Research on the sociology and process of science has addressed a range of issues related to social interaction, communication, and productivity in science. The social relationship of *friendship*, however, has largely been overlooked by the social sciences and in particular, by science (Dreher 2009, Grey and Sturdy 2007, O'Connor 1992, Spencer and Pahl 2006). Because of the value- and trust-based characteristics of friendship and the solidarity that it induces, it follows that this type of relationship may have an effect on the way in which scientists work and the outcomes of their work. Given these assumptions, the purpose of this dissertation is to explore 1) the presence of friendship in the academic scientific community, and 2) its role in academic productivity from a social network perspective. The social network perspective focuses on the relationships between pairs of agents that connect them to larger relational systems (Scott 1988). For the purpose of this work, this perspective is particularly valuable because it allows the examination of friendship as a specific type of strong network tie and its complexity and importance with regard to individual outcomes. Friendship is somewhat of an invisible factor in science, and although many have demonstrated the importance of personal relationships, they have not explicitly acknowledged it (Lee and Bozeman 2005, Jons 2007, Gersick et al. 2000, McFadyen et al. 2009, Rost 2011). To explain the prevalence of friendship and its effects on academic science, the dissertation integrates a broad and multi-disciplinary body of work, including social network theory, sociology, philosophy, economics, anthropology, science, the sociology of science, and technology policy. Of this work, social network theory, specifically, networked social capital provides a valuable framework for this study. To provide a starting point for this work, this chapter includes a brief overview of the rationale for the focus on friendship as a possible factor in academic productivity, and then to illustrate the types of friendships observed within the context of science, it reviews several biographies of prominent scientists. The chapter concludes with an overview of the structure of this dissertation.

1.1. Friendship and Academic Productivity: Network Perspective

Why would we be concerned with the highly personal relationship of friendship within the context of science? Studies of science have focused on trying to explain the inequality of the distribution of publications first documented by Lotka (1926) almost a hundred years ago. A useful framework for examining the presence and the role of friendship in science is that of networked social capital (Lin 1999, 2001). This framework is premised on the idea that individuals, through their network connections, can mobilize various valuable resources that hold important implications for a broad range of individual outcomes (Lin 1999, 2001). In this case, the outcomes may involve publications, grants, or other career outcomes. Research productivity in science is typically measured by the count of peer-reviewed publications. Nevertheless, its distribution is highly unequal: A few prolific individuals account for most of the publications while most scientists publish nothing (Abramo et al. 2009, Fox 1983, Long 1992, Long and Fox 1995, Price 1963, Maske et al. 2003, Ramsden 1994, Sax et al. 2002). This inequality raises the following question: What social factors inherent in networks may explain part of this puzzle?

Research has pointed to a range of factors, including social capabilities and standing, that could determine observed publication inequalities of the "productivity puzzle" (Cole and Zuckerman 1984). Scientists exhibit a variety of social capabilities, including those of obtaining knowledge production opportunities, pooling relevant resources from various sources (often dispersed) effectively and efficiently, exchanging and combining knowledge, validating knowledge, and finally disseminating knowledge (Bozeman et al. 2001, Cole 1992, Levin and Stephan 1991, Mulkay 1979, Nahapiet and

Goshal 1998, Nonaka and Takeuchi 1995). These capabilities are tightly coupled with the professional and social relationships in which scientists engage. More specifically, *social networks* comprised of the professional relationships of a scientist along with his or her knowledge and skills determine the social capabilities of that scientist (Bozeman et al. 2001).

Attention to social networks in the context of science has included observations of important productivity- and knowledge-related ties of co-authorship and knowledge-based citation ties (Beaver 2001, Lee and Bozeman 2005, Glanzel and Schubert 2005, Hansen et al. 2005, Lehmann et al. 2003, Wagner 2005, Wagner and Leydesdorff 2005, among others). More recently, attention to specific resources, or social capital, that is accessed via these networks has attracted the attention of the social science research community. From this work, the role of an individual's *social capital* has been identified as a critical piece of this productivity puzzle (Nahapiet and Goshal 1998). Social capital refers to social obligations that under certain conditions can be converted into economic or political capital (Bourdieu 1986). Within the context of science, social capital functions to mobilize the scientific resources available in scientists' quest for knowledge (Bourdieu 1991). Overall access to social capital is indeed based on social relationships, some closer than others, some with higher levels of trust than others, and some purely utilitarian; other social relationships may comprise close friendships, namely relationships characterized by both social and personal dimensions. From the perspective of social capital, friendship-based relationships within professional and other networks may provide various types of resources that extend beyond those of other relationships because of the intensely personal nature of these relationships (Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008, Uzzi and Spiro 2005).

In addition to the additional resources, personal relationships may help scientists to mitigate creative tensions inherent in the scientific profession. Such tensions arise from a discrepancy between the internal need for stability and external challenges created by the intrinsic normative ambivalence and paradoxes related to the conduct of science (Cole 1992, Merton 1973 [1949, 1963, 1968], Mitroff 1974, 1976). Studies of science suggest that the context of science is normatively ambivalent: Each of the established norms in science has a counter-norm, such as openness and universalism versus secrecy and particularism (Cole 1992, Merton 1973 [1949, 1963, 1968], Mitroff 1974, 1976). For example, a recent study of Japanese scientists observed that the traditional norm of open resource sharing in science is contradicted by institutional encouragement for the commercial application of research results; therefore, even scientists not engaged in entrepreneurial activities have changed their resource-sharing behavior (Shibayama et al. 2012). Similarly, a study of scientists' beliefs about university and industry relations found that different groups of scientists hold very strong and diverging beliefs about the separation of academic and commercial science and that these beliefs were a source of both convergence and conflict across these viewpoints among the faculty in the same schools and departments (Owen-Smith and Powell 2001). The primary problem associated with such normative ambivalence—the discrepancy between the norms of science, science and technology, science, and everyday life and the internal desires and external pressures of scientists—is that it results in contradictory behavioral requirements, which are a source of internal or external conflict (Pelz 1967, Owen-Smith and Powell 2001). Although some have argued that this discomfort or creative tension among forces pulling in different directions facilitates creativity and is conducive to the creation of new knowledge, it comes at a high personal cost (Pelz 1967), and it may impede collaboration between scientists even within a single organization (Owen-Smith and Powell 2001). Therefore, within such a context, personal relationships such as friendship may offer support by interpreting personal experience and helping to control the diversity of possible interpretations (Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008).

Empirical evidence primarily from the private sector documents how personal relationships affect productivity (Hansen 1999, Carillo et al.2008, Cross and Cummings 2004, McFadyen et al. 2009, Rost 2011, Tortoriello and Krackhardt 2010). Little is known, however, about the mechanisms by which personal relationships are utilized in the knowledge production process in general, or in the context of academic science. More importantly, we know little about how personal professional relationships affect the publication productivity of individual scientists. According to Fox (1983), a challenge for productivity studies is to examine the mechanisms of productivity in a manner that allows for disentangling the effects of the individual from factors related to the environment and other feedback. This dissertation proposes to fill the gap in the understanding of how productivity affects personal relationships by examining how friendship between scientists provides proprietary professional resources and ultimately affects their productivity. Scientists consult each other when they confront complex or ambivalent issues, and they exchange information and knowledge, free calculations, methods, equipment, and ideas for work in progress (Bouty 2000, McFadyen and Canella 2004, Nahapiet and Goshal 1998).

1.2. Anecdotal Evidence of Friendships in Science

A review of biographies of scientists provides anecdotal evidence of the role of friendship in scientific productivity. Such evidence is a useful starting point for the current work because it emphasizes the deeply personal nature of professional relationships, the most important distinguishing aspect of friendship. While friendship has been understudied empirically in the context of science, it has been referenced in numerous accounts of scientific processes and interactions. This review demonstrates that friendship between individuals emerges spontaneously and that it provides a motivation to persist, to collaborate, and to co-create. From these stories, it is evident that friendship is both a form of attachment and a culturally determined social relationship (O'Connor 1992, Pahl 2000, Spencer and Pahl 2006) relevant in the context of science (Anderson 2001). The observed lack of scholarly attention to friendship has been attributed to the Western cultural tradition of drawing a strict boundary between public and private life and placing friendship within a private sphere and treating it as a personal rather than social relationship (Anderson 2001, Grey and Sturdy 2007, O'Connor 1992). Nonetheless, studies of the lives of prominent scientists reveal the role of friendship in collaborative relationships, suggesting that a productive friendship is self-reinforcing, facilitates the efforts of scientists with complementary minds and personalities, eases their access to others, creates personal intellectual communities, helps scientists reinforce trust and solidarity, and sustains their efforts and persistence during academic life. In these biographies, friendship has been particularly evident among prominent scientists who have pursued novel ideas, exhibited intellectually courageous work that allowed them to break out of the established paradigms of the time, advanced unexplored fields, and were marginal and/or peripheral to their established scientific communities.

Among the most famous examples of friendships in the scientific environment were those among Charles Darwin, Sir Joseph Hooker, and Sir Charles Lyell; and Albert Einstein and his friends Michel Besso, Conrad Habicht, and Maurice Solovine, as well as his friend and intellectual rival Niles Bohr; and those between James Watson and Francis Crick; Pierre and Marie Curie (who were not only friends, but also life partners); and John Nash and Lloyd Shapley (Crick 1974, 1988, Darwin 2007, Isaacson 2008, Nasar 2001, Pycior et al.1996, Ridley 2009, Watson 1968). These stories underscore the potential importance of friendship in the scientific environment. To illustrate this notion, this work provides four selected cases of friendships of prominent scientists. The first is the friendship between James Watson and Francis Crick; the second is the friendships of Albert Einstein; the third is the partnership of Pierre and Marie Curie; and the last is the friendship between John Nash and Lloyd Shapley.

The Friendship of James Watson and Francis Crick

The story of the discovery of the structure of the DNA molecule describes a learning process that by far exceeds the formal boundaries of a single laboratory, university, or even a country. It is also a story of a friendship that originated from shared passion and that was formative for the academic personalities of James Watson and Francis Crick. As stated in the words of Crick, "…I would rather stress that the structure made Watson and Crick" (Crick 1974).

For American postdoctoral fellow James Watson, the quest began at an international academic meeting in Naples. Although primarily interested in genes, Watson had to study microbial metabolism and nucleic acid biochemistry, subjects that bored him. After viewing X-ray photos of DNA developed in Maurice Wilkins' laboratory, he realized that the structure of the DNA molecule could be a key to learning about genes. He attempted to obtain a position in Wilkins' laboratory, but did not succeed. In the fall of 1951, with the help of Salvador Luria, his mentor from Indiana University, Watson joined the Cavendish Laboratory at the University of Cambridge to work with John Kendrew. At Cambridge, Watson shared an office with graduate student Francis Crick.

It is said that Crick, like Watson, was also becoming increasingly bored with his research. Numerous accounts of the story say that the two "hit it off immediately." Before long, Watson's interest in DNA passed on to Crick, and they decided to beat Linus Pauling (an established American scientist working on the same issue) in the race to solve the puzzle of the structure of DNA (Lightman 2006). In a puzzle-solving exercise, their strategy was to "imitate Linus Pauling and beat him at his own game" (Watson 1968, p. 48). It is now well known that they partially succeeded and together with Maurice Wilkins won the Nobel Prize for Physiology or Medicine in 1962.

The story of Watson and Crick reveal several mechanisms through which friendship impacted the pursuit of knowledge. For one, the friendship between them emerged from and developed around the passion they shared about understanding the most central problem in molecular biology of the time: the genetic code. They recognized that understanding the structure of the gene might be a key to understanding the processes of heredity and reproduction, which was an issue of great promise at that time. They accepted the challenge and attacked it doggedly (n.d. nih.gov a and b). In spite of the gentleman's agreement within the British science community that this scientific problem "belonged to" Maurice Wilkins, they jointly committed to solving the same problem (Watson 1968). Their engagement was an action (Arendt 1998 [1958]), something they jointly believed in and wished to pursue.

Another way in, which their friendship impacted, their pursuit of knowledge was in their shared values and a passion for high quality science (in words of Kaufman (1992) the *techne* of science). In his memoirs, Crick (1988) wrote

> Jim and I hit it off immediately, partly because our interests were astonishingly similar and partly, I suspect, because a certain youthful arrogance, ruthlessness and an impatience with sloppy thinking came naturally to both of us (p. 60).

Their friendship enabled them to put in productive use the complementarity of their knowledge, background, and personalities. When they first met, Watson was in his early twenties and Crick in his mid-thirties. Both of their personalities have been described as abrasive (Maddox 2003, Hunter 2004), which is exposed in language used to describe them by various authors, including Crick and Watson themselves when referring to each other. While Watson was considered entrepreneurial and almost too bright (Crick 1974), Crick was considered intellectually self-confident, both charming and scornful. For example, Watson, in his memoir, says about Crick that he had never seen him in a modest mood and that the sound of his voice was often sufficient to make Bragg (head of the Cavendish laboratory) move to a safer room (Watson 1968:9).

Their bond of friendship was also strengthened by their collaboration. Watson's background was in viral and bacterial genetics, and Crick's in physics and X-ray crystallography. Together, they were described as having a character structure of the "interdependent collaborators" (Merton 1973[1968], p. 326). To solve the genetic puzzle, they had to draw upon the knowledge, expertise, and methods relevant to their work on problems in the fields of genetics, biochemistry, chemistry, physical chemistry, and X-ray crystallography. Neither possessed all of the necessary expertise or even a sufficient level of understanding of all the fields, which promoted their engagement in a process of active and social learning, described in the following quote by Ridley (2009):

> A shared passion for scientific gossip was the essence of this dyad. Because each told the other when he was talking nonsense, yet neither felt the least inhibition about sharing speculative thoughts, they could explore the ocean of the unknown without ever getting too far from the coast of facts (p. 49).

The interaction between Crick and Watson was referred to as "incessant chatter," which "maddened" others in their laboratory to such extent that they were moved to a separate room as soon as one became available (Ridley 2009:49). The intellectual exchange between Watson and Crick illustrates an aspect of friendship that Blatterer (2010) described as "normative flexibility," a property of friendship that allows friends to open up and experiment with societal norms and ideas, and to "speak the unspeakable" with a friend without fear of appearing incompetent and trusting that they will be competently called out for talking nonsense. Their friendship actually represents a relational phenomenon best described as "creationship," a relationship in which engaged parties can co-create (Lynch 2011).

In addition to strengthening their collaboration, their friendship sustained their collaborative efforts. Neither was paid to work on DNA. It was their curiosity, joint commitment, and scientific ambition, all of which helped them overcome the disappointments of failure, that prompted them to continue working on the problem, (Watson 1968, Crick 1988, Ridley 2009). Their mutual and sustained commitment created solidarity as well as the sense of ownership with respect to their issue, allowing them to overcome a series of obstacles such as the skepticism of their principals, lack of direct support from their institutions, lack of timely access to important information and expertise, as well as barriers created by personal ambitions and strained relationships.

Fourth, their friendships with other members of the scientific community allowed Watson and Crick to gain access to the information about activities of others working on the same issue. To illustrate, Crick and Wilkins were long time friends since the times they were fellow students at Kings' College. This friendship enabled Watson and Crick to access photos of molecular structures taken by Wilkins co-worker Rosalind Franklin. Wilkins and Franklin had a rather strained relationship, which hampered them in their work. In addition, both Watson and Crick had developed a friendship with a son of Linus Pauling, Peter Pauling, with whom they had shared office space. Pauling's son told them about the incomplete developments in Pauling's work (he learned about them from his father's letter) before anyone else knew. Armed with the knowledge that Pauling was wrong, Watson and Crick gained them a competitive advantage in the race toward solving the puzzle of the structure of DNA in that they realized that Pauling was wrong, and tried to understand how (for the full story, see Watson 1968).

Einstein and Friends

While the friendship between Watson and Crick illustrates the mechanisms of friendship in a process that led to a scientific breakthrough, the biography of Albert Einstein is a rich account of the intellectual friendships he formed throughout his lifetime as a scientist. The friendships of Albert Einstein tell a story of preference and the important of a commitment to a particular person over the norms and rules of the day. He was an independent social thinker, difficult to get along with, and at the beginning of his career, he worked in almost total isolation from the established physics community. Therefore, in his early career, his friends, including his first wife, were his primary intellectual partners and sounding boards for his ideas.

According to Isaacson (2008), during his university studies at Zurich Polytechnic, Einstein preferred studying with his friends (lectures there seemed obsolete, so friends studied more progressive work together). During this time, Einstein established a number of intellectual friendships that lasted and played an important role throughout his life. One such friend was mathematician Marcel Grossman, who shared his notes on mathematics with Einstein as a student and who was not only one of his discussion partners while they were studying together but also a contact that helped him obtain his first job appointment at the Swiss patent office and assisted him with the mathematics in Einstein's work on the theory of relativity (Isaacson 2008).

Other friends that served the role of a sounding board for his ideas during his early career in Bern were his first wife, Mileva Marich (she also was a physics student together with Einstein and Grossman), Michel Besso, Conrad Habicht, and Maurice Solovine. Michael Besso was a few years senior to Einstein at Zurich Polytechnic and shared several personality traits, intellectual brilliance and nonconformity. One aspect of their friendship was their disclosure of intimate details of their lives. In discussions with Besso about science, Einstein shared his ideas that later developed into this theory of relativity (Isaacson 2008). Similar to Grossman, Besso provided practical support. For example, he convinced his uncle, an established mathematician, to give recommendations for Einstein at the beginning of his career, when he had difficulty finding a job and struggled during the process of his divorce.

With his two other friends, Conrad Habicht and Maurice Solovine, Einstein established the "Akademie Olympia," a forum in which they took turns hosting "think-tank" sessions. They came together in informal settings to discuss readings that highlighted the intersection of science with philosophy as well as Einstein's own work (Isaacson 2008). According to Isaacson, these discussions, which served as an impetus for Einstein to develop his own philosophy of science, continued in later correspondence with friends after they had moved. In one letter to Conrad Habicht, Einstein attempted to convince his friend to come to work in the patent office so that he would be less intellectually bored there. In that same letter, Einstein also shared his famous energy formula $E=mc^2$ (Isaacson 2008).

In sum, the case of Einstein emphasizes the importance of intellectual friendships in the process of learning and actual knowledge creation. While Einstein is known for his thoughtful experiments, his friends comprised his primary intellectual community. These friendships were particularly important in light of Einstein's isolation from the established scientific community at the time. Furthermore, Einstein's friendships illustrate another important element of intellectual relationships: The basis for mutual liking is the fascination with each other's intellect and shared passion for science. Some of friendships Einstein formed through common experiences such as studies at Zurich Polytechnic while others he formed through shared intellectual pursuits and attraction. In one such instance, Solovine came to Einstein to take physics lessons, but they ended up establishing the above-mentioned informal discussion club. Similarly, Einstein became friends with Max Laue, who was a secretary of Max Plank. The two became fast friends after hours of physics discussions in which Einstein captivated Laue's intellectual curiosity to the extent that he published a number of papers based on the Einstein's theory of relativity. Other friends of Einstein included Paul Erenfest, a young physicist from Vienna (who also possessed a great love for physics and was marginal with respect to the established science community), and mathematician and rival David Hilbert (Isaacson 2008). Einstein was also was close friends with Niles Bohr, who, like Einstein, was a social thinker (Kumar 2011).

Partnership of Pierre and Marie Curies

The partnership between the discoverers of radioactivity, Pierre and Marie Curie, is an example of how complementary personalities, cognitive styles, and motivations facilitate the efforts of knowledge creation and ultimately induce productivity and success in a scientific career. In the case of the Curies, their personal relationship facilitated a productive union between two scientists with very different cognitive styles and personalities. Marie's background lay in chemistry and Pierre's in physics. However, both were committed to the solution of the same scientific problem related to radioactivity. Although as a physicist and a male, Pierre "naturally" occupied a scientific and social hierarchy above that that of his wife, a chemist and a female, in this partnership, it was Marie who was the entrepreneurial achievement-oriented partner.

According to Pycior et al. (1996), Pierre and Marie were exceptionally talented scientists with complementary minds, personalities, and scientific styles. Pierre Curie was a slow and sober thinker who cared little about such things as prestige and fame. He was wholly committed to familial science, a practice in which he brought his family into science, and treated all his coworkers as if they were members of his family (p. 16). He actually chose to live in the laboratory to be close to those he loved. Marie, in turn, was bold, sought recognition, and was very persistent. She was described as courageous and entrepreneurial, someone who moved quickly from experiments to bold published hypotheses. These contrasting personality traits contributed to the interdependence of Pierre and Marie and their complementarity was such that it allowed the couple to collaborate on equal terms and to achieve recognition in the scientific community. For ambitious Marie, being married to a talented and non-competitive scientist at that time enabled her not only to be a scientist but also to receive equal credit. For unassuming Pierre, being married to a talented, ambitious, and bold scientist allowed him to achieve scientific eminence that, given his absolute indifference to notoriety, priority, and reward, probably would not have been possible.

Love-like Attraction of John Nash and Lloyd Shapley

While the friendships of Einstein and the Curies lasted a lifetime, the friendship between Watson and Crick dissolved after Watson publicly exposed intimate details about Crick. Unlike any of these friendships, he friendship between mathematicians John Nash and Lloyd Shapley is said to have been intense and short lived (Nasar 2001). In fact, their friendship resembles a love affair: Lloyd Shapley was said to be the first in a series of emotional attachments of Nash to other brilliant mathematical rivals. Their friendship, like that of Watson and Crick, is an example of an attraction between two minds that are compatible yet challenging to each other. In fact, it was Shapley who described Nash as someone with a keen, logical, and thus beautiful mind (Nasar 2001).

The two met at Princeton University, where both were students. According to Nasar (1989), by the time Shapley arrived at Princeton in 1950, Nash was a second-year student well regarded by professors. However, his fellow students thought of Nash as someone who was not able to feel anything resembling love, friendship, or sympathy.

The affectionate love-like relationships Nash developed are said to have usually started with mutual admiration and passionate intellectual exchange, which then turned one-sided, and sooner or later ended with Nash's rejection. It is said that when the two first talked about mathematics, Nash "wowed" Shapley. For Nash, Shapley was one of the very few people at Princeton that could hold his attention and challenge him in mathematical discussions and therefore help him to further develop his reasoning. In addition, Shapley was popular both among students and faculty. He was a war-hero and the son of a prominent Harvard astronomer (Harlow Shapley). According to Nasar, in the eyes of Nash, who was starved for affection, Shapley had all one could wish for. At the time, Nash was considered an outcast, and as Shapley was openly admiring and sympathetic, he captivated Nash. While their friendship did not last long, and later on, Shapley actually denied it ever existed; Shapley was one of the few people who made sure that Nash received credit for his contributions to science. Although Nash suffered from schizophrenia, Shapley nominated him and made sure that he received the prestigious Von Newman's Award in Mathematics. According to Shapley himself, this effort was for Nash's son so that he would know that his father had achieved something great in his life (Nasar 2001).

Prominent Friendships in Science

The cases above provide a useful starting point for the exploration of friendship in science. These cases suggest that friendship may indeed play a role in its execution of scientific work as well as in the professional networks of scientists (Crane 1972, Davenport and Hall 2002, Adler and Haas 1992, Kadushin 2012, Polanyi 2000, Leydesdorff and Wagner 2008). These accounts provide evidence of the emergence of particular aspects of friendship that may be important: trust and solidarity built on flexibility, morality, and a commitment to a particular person. The case of Watson and Crick illustrates the role of mutual trust and solidarity reinforced by their friendship, the importance of normative flexibility in learning and co-creation, and the outcome of friendship when one friend breaches this trust and exposes intimate details about a friend to the public. Friendship between the two dissolved after Watson published his account of the discovery of the double helix, in which he revealed intimate details and even judgments about Crick's personal life and tastes.

The case of the friendships of Albert Einstein illustrates the importance of friendships for a peripheral scientist, a social thinker and morality reflected by a commitment to a person that superseded the norms of the day. Einstein's friends consistently chose him over the accepted values that dominated not only science but also politics in many of the European countries at the time. Because of this commitment, Einstein was able to overcome the difficult turning points of his life and career. The case of the partnership of Pierre and Marie Curie exemplifies a relationship that united two great and complementary scientific minds and personalities. Finally, the case of the friendship between John Nash and Lloyd Shapley is representative of a love-like attraction of compatible minds, but unlike the other cases, this relationship lacks flexibility and commitment. As mentioned, most of Nash's friendships were short lived because as they became closer to him, they were repelled by his rationality and selfishness. Both Nash and Watson have been described as *enfant terrible*, tolerated by others because of their intelligence, but not loved.

Altogether, these cases illustrate how friendship accommodates (or not) a high valuation of a friend as well as the quality or beauty of science, or its *techne* (Kaufman 1992). More importantly, these cases demonstrate how scientists mobilized all the available resources in the pursuit of knowledge (Bourdieu 1991). In addition, they suggest the potential role of friendship in science, a relationship that integrates the networked social context of knowledge production and helps scientists to adapt to external changes, deal with the pressure of the normative ambivalence of their workplace (Cole 1992, Merton 1973 [1949, 1963, 1968], Mitroff 1974, 1976, Pelz 1967), and persist in the face of challenge in their scientific careers (Etzkowitz et al. 1992, Duberley et al. 2007).

1.3. Research Questions and Dissertation Overview

This dissertation focuses on a particular form of relational social capital within professional academic networks: <u>friendship</u>. The purpose of this dissertation is to uncover the prevalence of friendship in science and explain its importance in the productivity of academic scientists. Specifically, I ask the following research questions as a foundation for this study:

- *How prevalent is friendship in academic science?*

- *How does friendship affect the exchange of resources such as knowledge, advice, and endorsements of the reputation and introductions to potential collaborators relevant to productivity in the professional networks of academic scientists?*
- *How does friendship affect scientist's publication productivity?*

By addressing friendship, the core research problem that this dissertation addresses is aspects of the social determinants of a scientist's publication productivity. This research involves an assessment of the presence and the prevalence of friendship in academic science in order to establish the extent to which friendship is observable in this context and the way in which it varies across the scientific community. The overall rationale, however, is to determine whether and how it matters in the productivity of academic scientists. Thus, the research is structured to address what productivity-related resources are provided through the professional networks of academic scientists and ultimately how they matter to academic production.

The foundation for this dissertation is rooted in the concept of networked social capital, which emphasizes the significance of social relationships as a resource for social action and the attainment of individual and organizational goals (Bourdieu 1986, 1991, Burt 1992, Coleman 1988, 1994, Lin 2001, 2002, Nahapiet and Goshal, 1998, Portes 1998). In the context of academic science, personal professional networks are a part of scientists' science and technology (S&T) human capital (Bozeman et al.2001), a source of their social and political capital (Bourdieu 1986, 1991), and ultimately a factor of productivity (Merton 1973, Bourdieu 1991, Nahapiet and Goshal 1989, Stephan 1996, Bozeman et al. 2001). Chapter Two provides a detailed review of the literature pertaining to social networks, social capital, and friendship from anthropology, philosophy, sociology, and studies of science, all of which are relevant to the understanding of the prevalence of friendship and its impact on the scientific community. The chapter also includes a synthesis of this body of literature using the lens of the networked social capital that provides the foundation for this dissertation and presents specific testable hypotheses that address the prevalence of friendship and its effects on academic science along with the overall dissertation model.

Chapter Three provides a detailed description of the empirical models that are developed to test the hypotheses articulated in Chapter two. It also provides details on the data that are used in this study and the analytical methods that address the core research questions and test the hypotheses presented in Chapter Two. The data were drawn from an extensive and detailed U.S. National Science Foundation-funded social network survey of academic scientists in the United States "Women in science and engineering: Network access, participation and career outcomes" (Grant # REC-0529642). The survey affords detailed data on the personal ties, including friendship ties, among academic scientists, allowing a unique and robust look at these relational ties within the social networks of scientists. Data analysis includes detailed descriptive statistics and a series of regression models designed to test the prevalence and effects of friendship in science.

Chapter Four presents the descriptive and statistical findings of the analysis. The chapter is organized in three sections: The first provides results that discuss the extent to which friendship exists in academic science, including an analysis of how it varies across groups, disciplines, and other factors. The second explains the effects of friendship on the mobilization of the network resources. The third presents the results of the core explanatory model for this dissertation. The model determines the effects of friendship on the publication productivity. Chapter Five concludes with a discussion of the theoretical contributions of this work as well as its implications for policy and applications in academic institutions.

2. A REVIEW OF THE LITERATURE

Friendship, seen as a source of social solidarity, or a form of "social glue" (Pahl 2000, Spencer and Pahl 2006), is omnipresent in human life, (O'Connor 1992) yet it largely remains neglected in organizational studies and the social sciences (Grey and Sturdy 2007, O'Connor 1992). Although studies of the social structure of science have alluded to the role of friendship, they have not directly addressed its prevalence or its effects. The purpose of this dissertation is to fill this gap of knowledge.

To address the role of friendship in the context of academic science and with respect to academic productivity, this chapter will draw from a broad range of work in social network theory, social capital, philosophy, anthropology, and sociology. More importantly, it examines these issues through the lens of *networked social capital* by discussing relevant aspects of the relational, structural, and resource characteristics of social capital and mobilizing these resources for individual goal attainment, particularly publication productivity in the context of friendship in science. Studies of social capital have shown that individuals function within networked societies in which individuals and groups are linked via various types of relationships, which in turn provide resources and have implications for a range of outcomes (Kadushin 2012, Lin 2001). The social capital perspective focuses on the effects of social connections and places them into a broader discussion of capital (Portes 1998). It examines how non-monetary benefits can be a source of opportunities, power, and/or influence, and affords a competitive advantage (Burt 1997). Sociologists attribute the origins of the systematic use of the social capital concept to Pierre Bourdieu and James Coleman (Adler and Kwon, 2002, Glanville and Bienenstock 2009, Portes 1998). From a network perspective, friendship is one type of tie between individuals that may play a different role in social structure or be a unique kind of resource, one that differs from other ties (Kadushin 1995, Krackhardt and Kilduff 1990, Smith-Doerr and Powell 2005). Addressing friendship within a framework of social capital provides a greater understanding of how these relationships may be a source of advantage (Burt 1997, Lin 2001).

This chapter is organized as follows. It will first review the essential components of the networked approach to social capital. As will be discussed, social networks are personal and have both (a) relational, and (b) structural properties (Wellman 2007). The main distinction between the two is the focus of the first (a) on the content and properties of relationships, and of the second (b) on the configuration of these relationships. The relational properties of social networks, which refer to the properties of relationships or ties in these networks, are related to social attachments and incentive considerations (Elfenbein and Zenger 2010, Nahapiet and Goshal 1998). Structural properties, which refer to the configuration of these ties, are related to the issues of access to various resources these configurations afford (Burt 19992, Nahapiet and Goshal 1998). Given these definitions, the second focus of this chapter is on the relational aspects of networks, with special attention devoted to friendship as a key network relationship. The chapter will then discuss the inherent structures of networks that have implications for resource provision and subsequent outcomes and the structure of social networks, specifically network size in the context of the number of friends in a scientist's network. Then, because the network framework examines the resources accessed through and mobilized from network relations (particularly friendship), the chapter continues by discussing its importance and then addressing its relationship to outcomes. The literature addresses network relationships not only from a general social network perspective but also within the context of science. The final part of the chapter will present a summary model that provides a synthesis of this review, resulting in an overall framework for this dissertation, and an analysis of the prevalence and the role of friendship in the professional networks of academic scientists and engineers. The model places friendship within the framework of networked social capital and depicts the ways in which it may potentially affect academic productivity. It consists of three sets of constructs denoting 1) a scientist's human capital and social characteristics; 2) social capital conceived as networks of professional relationships, the resources scientists have accessed through these networks, and the resources that scientists mobilize for the purposes of productivity; and 3) a goal, the attainment of which is aided by mobilized resources. The model rests on two assumptions about the context of academic science: First, productivity is a positive function of production factors distributed across individuals (Stephan and Levin 1992), and second, scientists invest in their relationships by pooling all the resources that they need to advance scientific knowledge (Bourdieu 1991, Lin 1999).

2.1. The Networked Structure of Social Capital in Science

In a networked framework, social capital is embedded in the networks of social relationships. In the context of science, networks consisting of research collaboration are directly relevant to publication productivity (Kraut et al. 1987-88, Guimera et al. 2005, Lee and Bozeman 2005, Stephan 1996). Studies of the motivation for collaboration reveal that individuals do so to adapt to increased research specialization by dividing the labor and by accessing or pooling complementary resources such as expertise, tacit knowledge, equipment, or funding necessary in their knowledge pursuits. These activities lower the opportunity costs and help them to diversify their research portfolios (Beaver 2001, Fox and Faver 1984, Kraut et al 1987-88, Katz and Martin 1997, Melin 2000, Stephan 1996, Thorsteinsdottir 2000). In other words, individuals invest in their social connections with expectation of future returns, a notion suggested by social capital theory (Lin 1999, 2001). The initial location of individuals within a broader social structure affects the level of resources that individuals have access to through their networks, and their purposeful activities affect the levels of resources they can mobilize from their networks (Lin 1999, 2001). Such a view of social capital is a useful lens through which the effects of personal professional relationships in academic science can be assessed. After all, the networked and hierarchical nature of science, in which productivity is primarily determined by one's structural location and access to production resources and personal professional networks, is a source of information and support (Bourdieu 1991, Long and Fox1995, Long 1978, Polanyi 2000).

Scholars have addressed the content and function of social capital in various ways. According to Bourdieu (1986), social capital is both an individual and a collective asset comprised of social obligations ("connections") and is "convertible, in certain conditions, into economic capital and may be institutionalized in the form of a title of 'nobility'" (p. 243); it consists of actual or potential resources embedded in the network of relationships of mutual acquaintance or recognition, and "the profits which occur from membership in a group are the basis of solidarity which makes them possible" (p. 249). While profits are primarily individual, they are related to being part of a group, or a network of relationships (not single relations). Social capital has also been defined functionally as "a variety of different entities" that (a) "consist of some aspect of social structure" and (b) "facilitate certain actions of the individuals who are within the structure" (Coleman, 1988:302). Coleman distinguishes three forms of social capital: obligations and expectations, information channels, and social norms.

Scholars who addressed the structural aspects of social capital posit that networks with distinct properties facilitate or impede the outcomes of individual actions (Kadushin 2004). For example, in a network comprised of a number of direct ties (i.e., the size of a network), social capital may come from the diversity or heterophily of its nodes, especially in terms of status (Lin 2001), from structural density with high closure (Granovetter 1985, Coleman 1988, 1994), from a sparse structure full of structural holes or disconnections between individuals (Burt 1992, 2005), or from both closure and structural holes (Burt 2005). Similarly, a source of social capital may be ties with certain characteristics, such as strong or weak ties (Granovetter 1973, Gulati 1995, Larson 1992, Inkpen and Tsang 2005).

In the context of science, in which informal networks shape the social context in which knowledge is produced, social capital is considered an essential and conjoined part of the scientist's scientific and technical (S&T) human capital (Bozeman et al. 2001, Bozeman and Rogers 2002). Through a process of learning and forging relationships, scientists form personal professional networks throughout their careers (Dietz 2000, Murray 2004). S&T human capital entails the entirety of individuals' scientific and technical knowledge, work relevant skills, and social ties and resources (Bozeman et al. 2001). As individuals move from project to project and from institution to institution, they form new ties that may provide opportunities, information, or sources of other benefits. In the words of Dietz and Bozeman (2005), scientists are "a walking set of knowledge, skills, technical know-how and, just as important, a set of sustained network communications, often dense in pattern and international in scope" (p. 420). These networks of communication not only link scientists to their broader science communities but also provide a source of potential productivity-relevant resources and serve as an important determinant of a scientist's knowledge production capability (Bozeman et al. 2001).

The remainder of this chapter highlights the aspects of networked social capital within the context of science. First, it presents the relational properties of networks and networked social capital, linking individuals via numerous types of relationships, including (potentially) friendship; therefore, relational ties are critical to this dissertation. Although the existence of friendship in science is important to establish, it may not be pervasive across all network members. Hence, the structural properties of networks, particularly network size, become important. For example, some individuals are likely to have more friends in their networks than others. This structural property is addressed in the second section below. The third part of the chapter discusses the key questions of this dissertation: Do friends provide more resources, or social capital, for academic scientists; and are friends different from other colleagues in what they bring to the collaborative relationships? Then the chapter addresses the resources provided through networked relationships. The next section of this chapter discusses the value of social capital in a networked environment by examining the role of social capital in increasing the outcomes or benefits to individuals. A particular area of interest in this dissertation relates to the issues of productivity in science, specifically the production of published research (journal articles) by academic faculty. The chapter concludes with a synthesized depiction of the prevalence and the role of friendship in academic science and presents the overall model of this dissertation.

2.1.1. Relational properties: The prevalence of friendship

Individuals in social networks are connected via "ties." One impetus for the development and perpetuation of social ties is increased specialization (Granowetter 1983). In the context of science, the extent of research specialization has been linked to that of publication productivity (Leahey 2006, Leahey et al. 2008, Stephan 1996). However, not all ties are the same, nor are they limited to a single type of tie (Monge and Contractor 2003, Wasserman and Faust 1994, Wellman and Wortley 1990). In network language, ties represent various types of relationships, or "relational properties," suggesting that either similar or different motivation, interactions, experiences, background, or other factors tie individuals to one another. The key ties of interest in this dissertation are professional relationships that involve friendship. Importantly, all friends are professionally related or "tied" to one another, but not all professional ties involve friendship. These ties vary by both internal properties, such as aspects of motivation and the role of structure in relationships, and external properties, such as trust and solidarity generated by relationships involved individuals. A social relationship develops over time from repeated interactions, each of which determines the course of the relationship (Hinde 1976). More importantly, while relationships are necessitated by the interdependencies of specialization, individuals may maintain their relationships because they may do so voluntarily by intentionally forming a friendship or because they are motivated by some kind of internal or external force such as compensation or the possession of expert knowledge, tradition, moral, and ethical beliefs, and/or persuasive ability. Despite or perhaps because of its very familiarity, the word "friendship" warrants defining, and a careful exploration of the origins of our ideas about the concept. While a commonly used term, the foundations of friendship vary across disciplinary communities. Sociological, anthropological, and other social science communities typically conceptualize friendship in relation to but distinct from kinship, sexual relationships, and professional relationships (i.e., those of paid work) (Grey and Sturdy 2007). By contrast, the humanities, such as law and philosophy, see friendship as a main organizing principle of a human society (Kaufman 1992).

Among the philosophical accounts of friendship, three aspects of friendship emerge: mutual caring (or love), intimacy, and shared activity (Helm 2009, 2010). The Western meaning of friendship has been greatly influenced by ancient Greek philosophy in which friendship, or *philia*, is understood as one of the three expressions of love (Helm 2009). Unlike *agape*, a love for a God or humankind in general, or *eros*, a passionate (sexual) desire for an object, *philia* refers to the platonic feelings we have toward particular individuals, family members, or the fellow citizens of one's country. An important feature of *philia* is that it is rooted in the special concerns friends have for each other and in the responsiveness to the properties of its subject, particularly goodness or beauty (Helm 2009). Responsiveness to a friend's goodness, in turn, allows for normative or ideal qualities such as those described in the terms of Aristotle's friendship of virtue to be assigned to the friendship.

Aristotle spoke of three kinds of friendships: those of pleasure, utility, and virtue (Helm 2009, Doyle and Smith 2002). Friends for the sake of pleasure are appreciated because of the joy they bring. Friendship of pleasure is thought to exist primarily between young people because their lives are regulated by their feelings, and their motivations are primarily are grounded in their own pleasures and opportunities at a specific moment. Because affections change rapidly, young people engage in and disengage from friendships quickly. However, given that friendship brings satisfaction, they are likely to spend more time together because it is a way to fulfill their common motivations. Friends of utility are also appreciated for instrumental reasons. Given that utility changes with circumstance, such friendships break up easily as soon as the common needs are met. Such a friendship is said to prevail between the elderly because utility is said to be their greatest concern. Earlier in life, friendships of utility are prevalent between individuals whose primary orientation is to pursue their own advantage. Interestingly, friendships with foreigners are said to generally fall into this class (Doyle and Smith 2002).

While friendships of pleasure and utility are definitely motivated by the personal goals of convenience, hedonism, and use, Aristotle's friendship of virtue is motivated by *goodness*. As people in such relationships wish each other good and care for their friends for the sake of friendship, friendships of virtue can be seen as morally superior, as an action in the sense of a human condition (Arendt 1958), or a mutual involvement and "enactment of virtue" (White 1999, p. 79). In fact, as friendship and virtue are mutually reinforcing, they have a capacity to sustain themselves over time: Virtue itself is enduring, and friendship allows for the exploration and its practice. Furthermore, at the core of moral virtue lies intellectual virtue in the form of practical wisdom (Swanton 2010).

Within the context of the general professional environment, some of the more recent management and human resource literature have recognized friendship as an increasingly important architectural dimension of an organization (Dickie 2009). This body of literature has linked friendship to such individual outcomes as work satisfaction, commitment and turnover decisions, team climate, and interpersonal exchange, increased communication, respect, security, and trust among employees, and organizational stability and productivity (Dickie 2009, Morrison 2004, Mao 2006, Song and Olshfski 2008, Tse et al. 2008)). Mao et al. (2009) linked differences in workplace friendship patterns to both the bureaucratic organization and the organizational level.

The limited work that has mentioned friendships in science has suggested that academic friendships among peers and mentors may play an integral role in the education of academic scientists (Anderson 2001, Waghid 2006). According to Anderson (2001:134-140), many people have found their calling and interest in one field or another or come upon an idea because of their relationship with a particular person, and many scholars have become friends after their similar interests in and enthusiasm about a question or a scientific problem were ignited and their similar commitment to the pursuit of the truth became known to one another. Friendship may ease the execution of certain intellectual tasks; for example, in the context of scholarship, people often speak about honesty implied in friendship, about mutual passion for a subject, and the balance or absence of "jealousy, bigotry and folly" (Anderson 2001:138). In fact, the Aristotelian concept of *philia* (friendship) can be used with respect not only to the person, the family, or a country but also profession, including science. Kaufman (1992) argues that friendship coincides with the love of each friend's *techne*, an art or skill, or the methods employed in making something or obtaining an objective. The author suggests that among writers, friendship coincides with the love of the *techne* of literature, among philosophers with love of the *techne* of philosophy, and among legal professionals, judges, scholars, and practitioners with love of the *techne* of law (Kaufman 1992). Good friends desire to elevate each other's *techne,* and therefore mutually contribute to each other's professional ideals. By the same token, we may also think that within the sciences, friendship may coincide with the love of the friend's *techne* of science. In fact, biographical and autobiographical accounts of scientist's relationships as well as their writings about the organizing principles of science indeed speak about such shared love of the *techne* of science. Therefore, in the Aristotelian sense of mutual incitement of virtue, friendship provides an opportunity for individuals involved in the friendship to practice what they believe is good science.

To a certain extent, the importance of shared activities lies in the notion that intimacy in friendship is based on shared interests or values, and a "shared" pursuit of these interests is a part of friendship (Helm 2009). It is this mutual knowing that distinguishes friendships from mere professional relationships or interactions with strangers. After all, the true selves rather than the projected self-images of individuals in such relationships are more exposed, and mutual knowing indicates a deepening of self-knowledge. Thus, one element of friendship is that of learning and identity building. Besides friends knowing each other, this shared perception involves love, both for another and for the self in the sense of being united and comfortable with others and with oneself. Nevertheless, because of the inherent risks of being known, insecure individuals may be averse to such exposure and thus incapable of friendship (Spencer and Pahl 2006, p. 578).

Related to shared interests is that friendships also develop around shared activities (Hinde 1976, Feld and Carter 1998, Marks 1998, Vigil 2007) and values (Lazarsfeld and Merton 1954). In science, scientists specialize, collaborate, and engage in professional societies and other formal and informal organizations in which they have interest (Beaver 2001, Crane 1972, Davenport and Hall 2002, Adler and Haas 1992, Katz and Martin 1997, Melin 2000, Leahey 2006, Polanyi 2000, Leydesdorff and Wagner 2008). Shared activities are an important aspect of friendship because friends engage in *joint* pursuits and their engagement, at least in part, may be motivated by the friendship itself (Helm 2009). Despite its limited scholarly attention, friendship appears to be not only present in the workplace (Lee and Ok 2011, Mao 2006, 2009, Marks 1998, Morrison 2004, Song and Olshfski 2008, Tse et al. 2008) but in fact essential to the modern work organization (Krackhardt and Kilduff 1999, Kilduff and Krackhardt 2008), especially in industries of external economies[1] (Kadushin 2012, Uzzi and Lancaster 2003). Moreover, people are said to have a natural tendency to work with their friends (Uzzi and Lancaster 2003). In science, the shared interests and intensity of interaction may lead towards the emergence of personal relationships, which may lead to new shared activities such as collaboration (Beaver 2001, Melin 2000). Shared activities embed friendships in relatively dense networks of relationships with others who are in some ways similar to one another (Feld and Carter 1998). Networks of other social relationships (including professional), some of which are friendships and some not, affect the nature of the friendship through the norms and expectations developed in these shared contexts.

[1] External economies are "economies that a firm can obtain through the use of facilities or services 'external' to itself" (Hoover and Vernon 1962, cited from Kadushin 2012).

The reviewed research indicates the existence of a sufficient body of theoretical and practical suggestions that show that friendship exists among academic scientists. Scientists come together in disciplinary communities or in interdisciplinary groups due to shared substantive interests (Crane 1972, Adler and Haas 1992, Polanyi 2000, Davenport and Hall 2002, Leydesdorff and Wagner 2008). The argument that people have a tendency to work with their friends (Uzzi and Spiro 2005) has also been suggested in studies of collaborative preferences (Beaver 2001, Melin 2000). Close friendships evolve from existing formal relationships (Morrison 2004) and shared activities (Feld and Carter 1998). Hence, given that academic science is structured by constantly evolving consensus-based scientific opinion and requires personal both professional autonomy and interdependence (Polanyi 2000) and that friendship networks cradle opinion formation (Krackhardt and Kilduff 1990), it is plausible that a proportion of the personal professional relationships of academic scientists are friendships. Overall, this attention to friendship suggests that the scientific environment is likely not to be exempt from friendship-based ties among faculty. Therefore, I to establish a foundation for the thesis I propose that:

Proposition: Friendship is present among the relationships in the professional networks of academic scientists.

2.1.2. Structural properties: Variation in the prevalence of friendship

Studies of personal social networks have shown variations among not only personal ties but also the number of ties, overall, and in any particular category (Wellman 2007, Wellman and Wortley 1990). An important aspect of network structure involves network "size," which in the context of personal networks refers to a subset of other individuals with whom a focal actor is connected (Wasserman and Faust 1994). This subset of individuals is defined by particular role-relationships and reflects the size and the composition of one's immediate personal community (Kadushin 2012, Wellman and Frank 2001, Wellman 2007). Social network research has documented that both the size and the composition of personal role-defined networks vary across different groups of people. For example, extraverts tend to have larger personal networks than introverts (Stefanone and Jang 2007), and early-stage entrepreneurs have smaller personal networks than established entrepreneurs (Greve 1995). In the context of science, electrical engineers tend to have more collaborators than biology, life sciences, and physics researchers (Lee and Bozeman 2005); and women tend to have more female than male collaborators (Bozeman and Corley 2004). This section discusses factors, including overall seniority but also productivity-related accomplishments, that develop as the careers of academic scientists mature.

While networks themselves may vary, so may friendships. Studies of friendship in anthropology and sociology suggest a possible systematic variation across groups of scientists in the prevalence of friendship, or the number of friends among professional networks. Patterns of friendship vary according to the social division of a given society (Allan 1998, O'Connor 1992) such as status, values, class, culture, age, and/or gender (Adams et al. 2000, Doyle and Smith 2002, Lazarsfeld and Merton 1954, Sheets and Lugar 2005, Verbrugge 1977). In organizations, patterns of friendship may vary by status (Mao 2006), shared experiences, and interests (Grey and Sturdy 2007).

What explains this variation? Friendship studies have highlighted several important factors that may be important to the extent, or prevalence, of friendship among network ties. In particular, this work addresses the roles of the earlier mentioned shared activity (Feld and Carter 1998, Helm 2009), personal autonomy (O'Connor 1992, Oliker1998), age (Fingerman and Hay 2003), and status homophily (Lazarsfeld and Merton 1954,[2] Verbrugge 1977).

First, with respect to shared activity, research has documented that friendships develop from repeated interactions, with each interaction affecting the further course of relationships (Hinde 1976, Feld and Carter 1998, Marks 1998, Vigil 2007). Repeated interactions might increase the value of a relationship; that is, as the number of interactions increases, the number of roles a person plays may also increase, increasing the value of the relationship (Hruschka 2010). Given that social capital is cumulative and scientists maintain productive relationships over time (Bozeman et al. 2001, Bozeman and Corley 2005, Dietz et al. 2000, Murray and Graham 2007), we could assume that scientists with longer tenure in science have had more opportunities to meet others whom they regard as being close friends.

The second explanation for variation in the prevalence of friendship is personal autonomy, which is considered a necessary precondition of friendship dictated by its voluntary nature (Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008, O'Connor 1998, Oliker 1998, Bell and Coleman 1999). Personal autonomy enables individuals to follow their internal sentiments and to disregard or overcome external pressures of the professional environment, or interests (Carrier 1999). From this point of view, friendship is self-centered and primarily motivated by the individual's self. A choice to collaborate

[2] Lazarsfeld and Merton (1954) coined the concept to describe an observation that in racially mixed housing project friendships exist between both similar and dissimilar people (blacks and whites, in the case of their study).

with friends may be based on the personal preferences of scientists (Uzzi and Spiro 2005). As a professional group, scientists and engineers have a fair amount of autonomy over their choice of collaborators (Bozeman and Corley 2004, Katz and Martin 1997). In their study involving 451 scientists and engineers from U.S. academic research centers, Bozeman and Corley (2004) observed a number of distinct collaboration strategies. For example, they observed that some scientists chose a "mentoring" strategy (i.e., working with junior colleagues) whereas others chose a "cosmopolitan" strategy (i.e., working with diverse range of colleagues within and outside of their home institution).

Furthermore, the reciprocal altruism theory suggests that cooperative relationships such as friendship emerge through mutually beneficial social contracts (Kruger 2003). Workplace friendship can be perceived as a contract of a mutually beneficial and equitable exchange of resources between two individuals over an extended period of time (Vigil 2007). As a social contract, friendship implies mutual expectation that investments (e.g., time, empathy, and money) provided at one time will be reciprocated in one form or another at a later time. In the process of selecting friends, individuals appraise each other for their reciprocity potential. An individual's reciprocity potential consists of both their capacity to provide valuable resources that the appraiser might readily observe and access and the probability that they will actually invest in a reciprocal relationship, thus making their capacity available to the appraiser. Vigil argues that it is in one's best interest to form relationships with others who are of roughly equal capacity and at the same time relationships with a high probability of reciprocal investment. It is plausible to think that scientists and engineers in different academic and professional positions as well as career stages experience different levels of job autonomy that may impact their ability to select relationships in their personal professional networks. In the workplace context, not all individuals have the same level of work autonomy. Arguably, work autonomy in science is likely to increase with rank and tenure. Scientists in higher academic ranks have more job autonomy (McEvily et al. 2003), and their reciprocity potential is higher. Therefore, we could infer that the ability of these scientists to choose friends as collaborators is higher than that of junior scientists, who are still finding their way in science and therefore have less freedom of choice.

The third factor that may explain variation in the prevalence of friendship is an individual's age. A study of people's attitudes about their social relationships found that older individuals tend to have fewer ambivalent relationships in their networks and are more likely to view their relationships with friends and acquaintances as close (Fingerman and Hay 2003). Authors of the study explained these findings with the socio-emotional theory of selectivity (Carstensen et al. 1999, Lansford et al. 1998), which suggests that individuals are selective, including only the most rewarding relationships in their networks, and that close ties improve with age. The theory argues that the selection and the pursuit of social goals is contingent upon the perception of time and distinguished between two general categories of motives: those related to the acquisition of knowledge and those related to the regulation of emotion. When individuals perceive time as being open-ended, they value higher knowledge-related goals, so when time is limited, they value higher emotional goals. Thus, the association between the time left in life and age ensures age-related differences in social goals. Therefore, the primary concern of older adults is the regulation of emotions. They may dismiss their less rewarding relationships and retain close ones, and they tend to view their close ties with more positive feelings.

For younger adults, in turn, the primary concern is learning. To this end, they establish and maintain a variety of relationships that range from close to ambivalent, or even problematic.

A final factor that affects the accumulation of friends in networks relates to status homophily, which is stronger for some groups than others (Lazarsfeld and Merton 1954, Verbrugge 1977). In one study of friendship choice in the United States and Germany, Verbrugge (1977) found that status homophily was present in the friendships of virtually all groups, with the highest levels of status homophily observed for those with the highest education level, the youngest age, and the highest occupational prestige. Interestingly, this study observed that for those with a mid- or high status, the preference for friends of dissimilar status tends to be upward (toward more educated and more respected people). This observed phenomenon may be a manifestation of preferential attachment in social choices, which is an established phenomenon in network formation (Barabasi and Albert 1999, Merton 1973[1968], Dorogovtsev and Mendes 2003, Wagner and Leydesdorf 2005). In the context of science, we can infer that not only do senior scientists and engineers have more opportunities to meet and form friendships with others similar to them, but also they are also more attractive as potential friends than those who are less senior. It also makes sense to assume that scientists who have a stronger reputation or control more production-relevant resources are more attractive as potential friends.

The literature reviewed in this section suggests that the size and the composition of role-defined personal networks may vary across different groups of individuals. Patterns of friendship vary across groups of individuals defined by status, class, culture, age, gender, values, shared experiences, and interests (Adams et al. 2000, Doyle and

Smith 2002, Grey and Sturdy 2007, Lazarsfeld and Merton 1954, Verbrugge 1977). The variations are explained primarily by the shared activity, homophily, and autonomy (Lazarsfeld and Merton 1954, O'Connor 1998, Oliker 1998, Bell and Coleman 1999, Verbrugge 1977). Scientists build their professional networks throughout their careers (Dietz et al. 2000), and friendships develop in the context of ongoing activities from repeated interactions (Feld and Carter 1998, Hinde 1976, Marks 1998, Vigil 2007). Older individuals tend to view their social ties as closer than younger individuals (Fingerman and Hay 2003). Therefore, we can infer that scientists with longer tenure in science have more opportunities to meet others whom they consider close friends and more autonomy in their choice of their closest collaborators. Thus, given the importance of time in building and accumulating relationships and the tendency of people to be selective, to work with their friends, and to increase the value of their esteemed relationships, the requirements of individual autonomy and reciprocal altruism in friendship as well as age-specific differences in the ways in which individuals perceive their relationships, I hypothesize that the following:

H1: Senior academic scientists have more friends in their collaborative networks than junior academic scientists.

2.2. Social Capital and Productivity in Science

Social capital studies have identified a diverse range of resources that aid individual and collective goal attainment (Table 2-1). These resources can be broadly categorized as tangible and intangible. In the context of science, tangible resources are *information channels*, and *information*, *advice*, and *knowledge,* and less tangible resources are *opportunities*, *trust*, *norms*, *solidarity,* and other *integrative* resources (Bouty 2000, Bozeman et al. 2001, McFadyen and Canella 2004, Nahapiet and Goshal 1998).

In the category of tangible resources, the most often mentioned as being provided by networks is information (Burt 1992, Nahapiet and Goshal 1998, Bouty 2000), and in the context of science, it is knowledge (Phleps et al. 2012). Social capital research typically refers to information in terms of its novelty, relevance, non-redundancy, privilege, exclusivity, and timeliness of its access (Granovetter 1973, Burt 1992, Portes 1998). In the context of science, exclusive information and knowledge are exchanged in thematic networks, or invisible colleges of elite scholars with similar interests (Crane 1972, Lievrouw 1989, Price 1963, Zuccala 2006, Wagner and Leydesdorff 2005). A related but distinct resource in this category of network resources is a specific subset of knowledge: advice that individuals seek to fill gaps in their knowledge, or to solve problems more quickly (Coleman 1988, Nahapiet and Ghoshal 1998, Lin 2000, McGrath et al. 2003). Similarly, scientists routinely provide each other with practical professional support, which is particularly explicit in mentoring relationships in which senior scientists support their junior colleagues (Bozeman and Corley 2004).

Theoretical work on social capital has conceptualized network *relationships* as *channels* of information and other resources (Adler and Kwon 2000, Coleman 1988, Lin 2000, Nahapiet and Ghoshal 1998, Podolny 2001, Tsai and Goshal 1998). Therefore, conceptualized relationships are a primary network resource. In the context of science, collaborative relationships are the most important channels of resource exchange and a source of knowledge and expertise that scientists do not possess themselves (Beaver and

Rosen 1978, 1979, Beaver 2001, Fox and Faver 1984, Katz and Martin 1997, Thorsteinsdottir 2000). Such a take on relationships is manifested in research that examines the benefits of the number of direct ties (Podolny and Baron 1997, Lee and Bozeman 2005, among others) and the properties of these ties (Hansen 1999, 2002, among others). In other words, it is more likely that necessary information can be found among a larger number of contacts than a smaller number. In the context of science, Bozeman and Corley (2004) observed that academic scientists with more collaborators are more productive.

Table 2-1 Social capital: Sources, resources, mechanisms, and effects

Resources	Mechanisms	Outcomes (+/-)	
		General	The context of science
Information channels (Coleman 1988, Nahapiet and Ghoshal 1998, Lin 1999, 2000) Information and advice (Lin 1999, Adler and Kwon 2000) Knowledge (Nahapiet and Ghoshal, 1998) Opportunities (Loury 1987, Burt 1992) Influence (Lin 1999) Credentials (Lin 1999) Reinforcement (Podolny and Baron, 1997, Lin 1999) Control and autonomy (Baker 1992, Burt 1992) Mutual recognition and acknowledgement (Bourdieu 1986) Trust, norms, and effective sanctions (Coleman 1988, Farr 2004, Putnam 1993) Solidarity (Bourdieu 1986, Bozeman et al. 2001, 1991, Coleman 1988, Putnam 1993)	Facilitates flow of information (Lin 1999) Privileged access (Portes 2000) Reduces transaction costs (Adler and Kwon 2000) Supplies obligations, expectations, and social norms (Coleman 1988, Bourdieu, 1986) Allows the use of human and other capital (Burt, 1992, 1997) Ties may exert influence over agents who play a critical role in decisions involving the actor (Podolny and Baron 1997, Lin 2002) Reinforces identity and recognition (Podolny and Baron, 1997, Lin, 2001) Creates conditions necessary for a combination and exchange of intellectual capital (Nahapiet and Ghoshal, 1998) Joint rationality (Bozeman et al. 2001) Maintenance and reproduction of solidarity (Bourdieu 1986, 1991, Coleman 1988, Putnam 1993)	Social status or reputation, preservation of a dominant group (Bourdieu 1986) Mobility and pay (Podolny and Baron, 1997) Job satisfaction (Flap and Volker 2001) Performance (Burt 1992, 2001, Krackhardt 1999, Reagans and Zuckerman, 2001) Inequality, competitive advantage, cumulative advantages/disadvantages (Bourdieu 1986, Burt 1992, Loury 1987) New intellectual capital (Nahapiet and Ghoshal, 1998) Ability of scientists and engineers to contribute knowledge (Bozeman and Mangematin 2009) Creativity (Burt 2004) Skills and traits that are valued in the marketplace (Loury 1992) Future productivity (Farr 2004) Efficiency of economic capital (Adler and Kwon 2000) Collective action (Bozeman et al. 2001, Farr 2004)	Access to invisible colleges (Crane 1972, Lievrouw 1989, Price 1963, Zuccala 2006, Wagner and Leydesdorff 2005) Efficiency of problem-solving (Coleman 1988, Nahapiet and Ghoshal 1998, Lin 2000, McGrath, Vance and Gray, 2003) Professional support and mentoring (Bozeman and Corley 2004) Access to and exchange of complementary productivity-relevant resources (Beaver and Rosen 1978, 1979, Beaver 2001, Fox and Faver 1984, Katz and Martin 1997, Thorsteinsdottir 2000)

Not all resources, however, are as tangible as those described above. Network relationships also provide important, but much *less tangible* resources. First, an important resource emphasized by the networked perspective of social capital is an *opportunity* (Granovetter 1973, Burt 1992, Nahapiet and Goshal 1998, Uzzi 1998). Relationships with friends and other social contacts are sources of opportunities for individuals to use their human or financial capital, and they may also facilitate an awareness of entrepreneurial opportunities (Burt 1992, Singh 2000). For example, Granovetter (1973), in his classic study, found that people often find jobs through their acquaintances. In the context of science, social networks provide scientists with *opportunities* to engage in new research collaborations and projects, to obtain funding for their research (Katz and Martin 1997, Beaver 2001), and to actually engage in the co-creation of knowledge through exchange and combination (Tsai and Goshal 1998, Nahapiet and Goshal 1997).

Social capital theorists speak of other less tangible integrative resources as *trust and norms* (Putnam 1993), which are complemented by effective sanctions (Coleman 1988), recognition and acknowledgement (Bourdieu 1986), influence and credentials (Lin 1999), reinforcement (Podolny and Baron, 1997, Lin 1999), and solidarity (Bourdieu 1986, Bozeman et al 2001). Trust, typically associated with strong and/or close relationships, is considered a precondition of moving more resources between actors and the transference of located knowledge, especially tacit knowledge (Hansen 1999, Cross and Cummings 2004, Hansen et al. 2005, Podolny 2001). In the context of science, all of these less tangible resources are likely to have an impact on productivity. For example, trust within research collaborative networks is an important precondition for knowledge exchange because it mitigates the risk of being "scooped" (Stephan 1996). Another example of an intangible resource is the reputation of one's academic advisor or mentor, recognized as an important resource that facilitates the academic success of early career scientists (Crane 1969, Long 1978, Cole and Cole 1973).

Overall, the richness of both tangible and intangible resources that networks may provide highlights the potential benefits of network participation. The discussion above underscores the importance of informal networks as not only social ties but also a source of resources that aid the attainment of professional goals. However, the mere presence of these resources in one's network does not guarantee that individuals will actually benefit from them. The capital nature of network resources dictate that people must invest in their relationships if they are to mobilize them for their purposes (Lin 1999, 2001).

2.2.1. Mobilization of network resources

The opportunity to access network resources is important. However, an important distinction of the networked perspective of social capital is the distinction between accessed and mobilized resources (Lin 1999, 2001). Accessed resources refer to all of the resources embedded in the network of an individual's relationships. These resources are potential enablers of action that must be activated by mobilization. Resource mobilization refers to the *action of using and actually gaining benefits* from one's network. Broadly defined, it refers to obtaining network resources for personal goal attainment (Lin 1999, 2001).

In the context of academic productivity, the most important tangible resources mobilized from social networks are information and knowledge (Nahapiet and Goshal 1998, Lin 1999, Adler and Kwon 2000). A representative example of the *mobilization* of this type of resource and the role friendship plays in it are processes of a search for information from social networks. The organizational learning literature suggests that whether individuals seek information from their social networks or not depends on such factors as knowing the expertise of others, valuing their knowledge, being able to gain timely access to their thinking, and perceiving that seeking information from the respective individual will not be too costly in terms of the perceived risks associated with advice seeking (Borgatti and Cross 2003). People call upon their networks in situations that are uncertain because of a lack of information or ambiguity when they have too much of information or when the information is controversial (Saint-Charles and Mongeau 2009). According to several studies, when they do not have enough information, people seek out network ties that they trust in terms of expertise; when the situation is ambiguous, people seek out their friends.

In a highly competitive environment, individuals also feel more comfortable turning to their friend(s) for both information and advice (McGrath et al. 2003). In such an environment, advice seeking is associated with perceived social and professional risks (Westphal 1999). In such contexts, trust in the benevolence of the other party is what mitigates social risks, and trust in professional competence is what mitigates professional risks (Mayer et al 1995). An inherent property of friendship is benevolence; that is, friends wish one other good and care for them for the sake of the friend (Helm 2009). In terms of competence, knowledge of one's trustworthiness is higher in relationships that are multiplex (i.e., comprised of a number of roles) (Mayer et al. 1995).

Close relationships such as friendship promote both the seeking and the sharing of information (McGrath et al. 2003). Close relationships allow friends to access each other's thinking. As a result, they establish joint engagement in problem solving and shape existing knowledge to fit the problem at hand (Cross et al. 2001). These relationships are "safe" because they not only involve mutual trust but also accommodate a mutual lack of knowledge or divergent opinions (Cross et al. 2001, Blatterer 2010). In the context of science, this aspect of friendship prompts resource mobilization in both ambiguous situations when there is not enough information or when information is hard to grasp and situations when a "reality check" is needed (McGrath et al. 2003, Cross et al. 2001). In such situations, advisers have to become invested in the situation, take time to listen, provide feedback, or explain novel or complex ideas (Granovetter 1985, Uzzi 1998, Hansen 1999). An example of such exchange was the active social learning and "reality checks" that transpired in the relationship of Francis Crick and James Watson, presented in the introductory chapter. Multiple accounts of their friendship have highlighted the importance of their sharing of undeveloped thoughts and elaborating on them jointly, and trusting that neither would hesitate to express directly that something made no sense (Merton 1973[1968], Ridley 2009). Similarly, friends of Albert Einstein were his "sounding boards" throughout his live (Isaacson 2008).

Empirical research documents that multiplex and trusted relationships and the social cohesiveness of networks facilitate knowledge transfer, particularly when knowledge is complex or tacit (Hansen 1999, 2002, Levin and Cross 2004, Phleps et al. 2012, Podolny 2001, Reagans and McEvily 2003, Tortoriello and Krackhardt 2010). Trust and social cohesion associated with close relationships reduce competitive and motivational impediments (Reagans and McEvily 2003) and assure involved parties that transferred resources will not be misused (Krackhardt 1999, McEvily et al. 2003).

Empirical research also has found that it is friendship (not organizational links) that facilitates knowledge transfer when the knowledge is located in geographically distant locations (Bell and Zaheer 2007).

Thus, in the context of science, mobilization of network resources includes but is not limited to such activities as seeking and giving advice, accessing the thinking of others, and transferring knowledge, and because they encourage these processes, closeness and trust in relationships are important factors that facilitate resource mobilization. Professional friendships, by definition, are close and trust based, implying multiple roles, affection, and utility-based motives. Therefore, friendships likely facilitate the mobilization of resources from personal professional networks of academic scientists, which leads to following hypothesis:

H2: Scientists with more friends in their networks mobilize more resources such as advice, support, and co-authorship through their networks than scientists with fewer friends.

2.2.2. Productivity effects of social capital

In science, productivity is an outcome of a potentially collaborative process in which knowledge production factors, efforts, materials, equipment, knowledge, and skills of discipline-dependent relative proportions are combined (Levin and Stephan 1991). What distinguish science from other contexts is that it is not neutral (i.e., it may either facilitate or impede scientists' efforts) and that all relevant production factors are pooled from various sources (Fox 1983, Fox and Mohapatra 2007, Hemlin et al. 2008, Stephan and Levin 1992). Contextual aspects that affect a scientist's productivity include collegial exchange, colleagues' orientation and activities, and organizational freedom

(Fox 1983). Scientists pool all relevant and accessible resources such as equipment, data, methods, and knowledge from various sources from within and outside their respective institutions (Bourdieu 1991, Stephan and Levin 1992). Scientists accumulate their social capital throughout their careers (Dietz et al. 2000, Bozeman et al. 2001, Murray 2004). Social capital is embedded in professional networks, which are diverse, often spanning organizational, institutional, and national boundaries (Dietz 2000, Murray 2004). Social capital affects the ability of scientists and engineers to contribute knowledge, an important component of productivity (Bourdieu 1991, Bozeman and Mangematin 2009). In this process, networks of personal professional relationships provide support for efforts and are more likely to integrate the context in which knowledge production takes place. Another essential productivity factor is the social capabilities of scientists, determined by the quality of their relationships. Combined with other production factors—effort, materials, equipment, skills, and knowledge—social capabilities form a complete sufficient set of factors of productivity function (Levin and Stephan 1992):

Productivity = F (effort, material, equipment, skills, knowledge, and social capabilities).

The S&T human capital framework underscores that the main mechanism by which social capital affects goal attainment in science is joint rationality and solidarity, which bind individuals who pursue common goals (Bozeman et al. 2001). An important shortcoming of the S&T human capital framework is that it does not address the mechanisms by which social capital is useful. It posits that social capital must be utilized to become useful (Bozeman et al. 2001), but it does not explain the mechanisms through which the effects of social capital on productivity are realized.

How social capabilities impact productivity in science has been highlighted in the theory of the role of social capital, particularly in the creation of *intellectual capital*. Nahapiet and Goshal (1998) theorized that in contexts in which intellectual capital is created, the whole of the social capital consists of relational, structural and cognitive elements that affect four fundamental preconditions of the knowledge creation: gaining access to knowledge creation parties, anticipating that value will be created, providing motivation for exchange and combination, and ensuring the *combination capability*. The most important contribution of this theory is the distinction between the structural, relational, and cognitive elements of social capital. Structural social capital refers to the configuration of social networks; the cognitive dimension refers to shared language and narratives; and the relational dimension to the content and the properties of the relationships and to the above-discussed intangible network resources of trust, norms, obligations, and identification. According to this theory, the primary benefits of structural social capital are related to the acquisition of information; the primary benefits of cognitive social capital are related to the increase in knowledge combination capacity; and the primary benefits of relational social capital are trust and solidarity. While the distinction between the structural, cognitive, and relational social capital made by Nahapiet and Goshal is conceptually useful for understanding the complexity of the social context of academic productivity, the theory has several limitations. First, it was created within the context of a firm thus in the sphere of technology (Murray and Graham 2007). Second, it focuses exclusively on the stage of the actual creation of new knowledge through exchange and combination, thus leaving out the processes of the preceding and succeeding stages of knowledge production, obtaining opportunity, pooling resources, and validating knowledge contributions, and communicating and exchanging knowledge through publication (Cole 1992, Fox 1983, Merton 1973, Nonaka and Takeuchi 1995, Stephan and Levin 1992). Productivity in academic science, however, requires the *mobilization of all available resources* at *all knowledge production stages* (Bourdieu 1991), both tangible and intangible. Third, the distinction between forms of social capital, although conceptually clarifying, draws the focus away from the fact that the relational dimension of social capital is *intertwined* with both its cognitive and structural dimensions (Cole 1992, Bozeman et al. 2001, Podolny and Baron 1997). A small emerging body of empirical work has addressed the interplay between the quality of relationships and productivity in science. A longitudinal study of scientific publications of biomedical research scientists by McFadyen et al. (2009) found that researchers with sparse collaborative networks composed of mostly strong ties were among the most productive. Similarly, Rost (2011) found that because sparse egocentric networks composed of strong ties draw out the strength of those ties, they enhance innovation (measured as forward citations of patents). In the context of the firm, such integrated social capital facilitates productivity because involved parties are assured that the information or knowledge transfer will be mutually beneficial (Tortoriello and Krackhardt 2010, Uzzi and Lancaster 2003, Uzzi 1997).

2.2.3. The integrative and productivity effects of friendship

Does friendship facilitate the mobilization of the social capital of the friends for purposes of academic productivity? Prior work points to the mobilization of resources accessed through the network, and the integration of social capital, thus increasing the efficiency of mobilization and the use of network resources. Friendship integrates personal networks by creating joint rationality (Bozeman et al. 2001) and by supporting the maintenance and the reproduction of trust and solidarity within networks (Bourdieu 1986, 1991, Coleman 1998, Putnam 1993). As a result, it may create added value or "integrative social capital," that enables collective action (Bozeman et al. 2001), increases the efficiency use of human or economic capital (Burt, 1992, 1997), reduces transaction costs (Adler and Kwon 2000), facilitates performance (Burt 1992, 2001, Krackhardt 1999, Reagans and Zuckerman 2001), increases the ability of scientists and engineers to contribute knowledge (Bozeman and Mangematin 2009), and supports the creation of new intellectual capital (Nahapiet and Ghoshal, 1998). Social capital theorists underscore the importance of such integrative resources in the preservation advantages of dominant groups, inequality, and cumulative advantage and disadvantage (Bourdieu 1986, Burt 1992, Loury 1987). More importantly, these intangible resources, inherent properties of network relationships, do not exist outside of these relationships.

The capacity of friendship to mobilize these integrative intangible resources originates from its internal qualities: its *inherent flexibility and simultaneous stability*, its *morality and commitment* to a particular person, and its *multiplex role structure* (Blatterer 2010, Conradson and Lathan 2005, Hruschka 2010). First, the inherent flexibility of friendship refers to its normative flexibility (Blatterer 2010) and its adaptability to changing contexts (Becker and Johnson 2009, Conradson and Lathan 2005, Hruschka 2010). Quoting Emerson, who defined a friend as someone before whom one "may think aloud," Blatterer suggests that even though "thinking aloud is risky, because we may at times think the unthinkable," with our friends we can safely "speak the unspeakable" (2010: 40). With friends, one can say things that are "indecent" or questionable in the eyes of some judgmental or critical observer and even against our own best judgment. In the words of Blatterer (2010):

> Here then the feminist may, for a time, become sexist, the leftist conservative, the tolerant intolerant, the openhearted mean-spirited, the lover discursively "unfaithful." Close friends will make these allowances because they recognize one another's fallibility (and thus humanity) in the context of reciprocity, trust and nurturance (p. 40).

The same normative flexibility that allows friends to disclose themselves in a private situation without fearing to appear indecent in the eyes of their lover, husband, or general public (Blatterer 2010) may allow friends in a workplace to share incomplete thoughts and ideas without fear of appearing incompetent or being excluded if what they say makes little or no sense (Ridley 2009). Normative flexibility allows for the formation of consensus, the accommodation of disagreement and difference, and the expansion of traditional boundaries such as those determined by gender, class or any other ascribed status (Allan 1998, Blatterer 2010, Lazarsfeld and Merton 1954, McPherson et al 2001). With respect to the adaptability of friendship to changing contexts, empirical research provides evidence that regardless of distance, people tend to nurture their friendship networks (Conradson and Lathan 2005) and maintain well-developed, high-value relationships (Hruschka 2010). In fact, although real friendships are sometimes put on hold, they are not terminated, and when friends reunite, the friendship resumes as if had never been interrupted (Anderson 2001).

Another internal quality of friendship that enables it to mobilize these integrative intangible resources, morality, paired with the commitment to a particular person, makes friendship ties relatively impervious to social pressure (Blatterer 2010, Friedman 1989). Therefore, friendship has a capacity to mitigate conflicting demands external to a relationship. In science, this aspect of friendship is particularly important because of the above-discussed collaborative work and high personal and socio-emotional costs of the normatively ambivalent working context, which may arguably impede collaboration (Fox and Faver 1984, Pelz 1967, Owen-Smith and Powell 2001). According to Friedman (1989) "our commitments to particular persons are, in practice, *necessary counterbalances* (emphasis original) to our commitments, to abstract moral guidelines, and may, at times, take precedence over them" (p. 6). Researchers have observed that conflicts with friends facilitate learning and moral development (Bukowski and Sippola 1998, Haan 1985). Because such conflicts are more emotional, people are more likely to question their own opinions and evaluate the situation from the perspective of right or wrong (Carbery and Buhrmester 1998). It is important to note that commitment to a particular friend as opposed to abstract norms need not be considered immoral. Friendship implies a deep intimacy and shared values while implying love of the friend's goodness (Helm 2009, Anderson 2001), and/or *techne* (Kaufman 1992). If the joined conception of friendship involves the pursuit of virtue, then commitment to a friend would never require immoral action on behalf of a friend or friendship (Helm 2010, Anderson 2001). Finally, the commitment to a particular friend may also mean commitment to and enforcement of shared values. In the context of science, it has often been the case that friends monitor the proper allocation of scientific priority, one of the core values in science (Fehr and Fischbacher 2004, Maddox 2003).

Friendships are also multiplex. Professional friendships, by definition, imply multiple roles and span multiple contexts (Verbrugge 1979). More importantly, they introduce personal, non-working roles in the relationship characterized by a broad spectrum of interactions and many layers of different exchanges within the same relationship and across different roles (Ashforth et al. 2000, Hinde 1976). Empirical studies often treat the multiplexity of relationships as a structural measure of trust (Iset and Provan 2005). Two mechanisms ensure trust in multiplex relationships. First, layering multiple roles in a single relationship is a strategy that increases the value of relationships, but that is a defensive strategy against potential abuse in relationships (Hruschka 2010). Second, multiplex relationships are typically embedded in networks of other relationships, which ensures the trustworthiness of involved parties (Iset and Provan 2005). The most important aspect of multiplexity in the context of social capital is the capacity of such relationships to transfer capital created in one context to that in another (Bourdieu 1986, Hruschka 2010). In the context of science, instrumental roles in professional relationships often involve collaboration, a complex type of relationship in which both instrumental and personal motivations are present. As noted earlier, scientists collaborate not only to pool knowledge for solving complex problems and to access complementary resources such as expertise, tacit knowledge, equipment, or funding but also to harness the pleasure that collaboration brings (Beaver 2001, Kraut et al. 1987-88, Katz and Martin 1997, Melin 2000, Thorsteinsdottir 2000,).

Because of these unique relational properties, friendship may play a potentially important role in the integration of social networks. Friendship supports the emergence and perpetuation of trust and solidarity within the network, essential parts of joint rationality (Bourdieu 1986, Bozeman et al 2001, Coleman 1988, Putnam 1993). When individuals are committed to agreed upon goals and act to attain them, they can be viewed as being jointly rational (Bozeman et al. 2001), which, in turn, has been linked to more efficient use of human and other resources and increased performance (Adler and Kwon 2000, Burt 1992, 1997, 2001, Krackhardt 1999, Reagans and Zuckerman 2001). In science, joint rationality has also been linked to the increased ability of scientists and engineers to contribute knowledge (Bourdieu 1991, Bozeman et al. 2001, Bozeman and Mangematin 2009, Nahapiet and Ghoshal, 1998). Furthermore, because of its normative flexibility, friendship facilitates the emergence of shared cognition between collaborators, so it is instrumental in the creation and maintenance of cognitive social capital (Lin 1999, 2001). Trust associated with friendship increases the ability of involved parties to cope with complexity and serves to reduce uncertainty that is inherent in any social interaction (Coleman 1994, Nahapiet and Ghoshal 1998). The norm of cooperation implied by the reciprocal altruism of friendship (Vigil 2007) facilitates the motivation of engagement and an anticipation of results from joint activities. Similarly, norms of high valuation and responsiveness to diversity, openness to criticism, and a tolerance of failure are important in that they reduce the potential for the emergence of the phenomenon of groupthink and lock in (Smith-Doerr and Powell 2005).

Perhaps the most important added integrative value of friendship is solidarity (Bourdieu 1986). Because of its self-reinforcing nature (Skvoretz 1998), solidarity serves as an integrating and focusing factor in the pursuit of common goals (Bozeman et al. 2001). Friendship is a source of emergent solidarity because it provides the conditions necessary for the occurrence of the objectification and moral orientation of a group (conceived as a network of two or more individuals). It binds individuals into a “plural agent” (i.e., a group of people who jointly care about certain things) and provides members of the “plural agent” with “genuinely interpersonal reasons for acting, judging and responding emotionally" (Helm 2010, p.45). Allan (19988) suggests that equality is at the core of friendship-based solidarity, reflected in friends occupying similar positions within social structures (Adams and Blieszner 1994, Ueno and Adams 2006). This equality can also stem from the identification with a group and a sense of community (Rorty 1989, 1991). In some occasions, these solidarities can be value-based (Lazarsfeld and Merton 1954). The solidarities result in a differentiated valuation and treatment of friends and strangers (Halpern 1994, Uzzi 1998) as well as a consideration of another's best interests when one makes choices (Walhof 2006). More importantly, solidarities may be formal and informal, and either open or hidden (Spencer and Pal 2006, Smith-Droerr 2004). In the context of science, a formal solidarity is expressed in what is understood as the ethos of science; informal solidarities emerge in the "invisible colleges" or personal professional networks and circles of scientists, and hidden solidarities emerge in so-called "old boys networks." In science, solidarity is one of the preconditions of joint knowledge creation; it supports the joint pursuits of agreed-upon goals (Bozeman et al. 2001) and increases a scientist's ability to recognize opportunities for knowledge exchange. Therefore, it affects the anticipation of results from knowledge exchange and combination, and supports the motivation to participate in them (Nahapiet and Goshal 1998).

Well-developed relationships such as friendship may also reflect the extent to which individuals are integrated in the broader science community. Such integration may result in greater trust with respect to the quality of scientists (Merton 1973 [1972], Latour 1987, Wagner and Leydesdorff 2005). Thus, it is plausible to assume that scientists with greater integrative social capital generated by their professional friendships have an advantage in situations of uncertainty. According to Lin (2001), social capital facilitates goal attainment by signaling and affirming an individuals' capacity and demonstrating the potential resources that might be accessible to them (Lin 2002). This mechanism was observed by Murray (2004), who found that one of the motives for biotechnology firms to collaborate with academic scientists was that such collaboration signaled to their investors that their work was scientifically sound and on the frontier of knowledge. Moreover, a vital aspect of social capital is that it transcends contexts and resources that are created in one context but that can be transferred to other contexts (Bourdieu, 1986). Therefore, professional networks composed of friendships, which by definition imply multiple roles spanning multiple contexts and/or containing both social and personal dimensions, are qualitatively different from networks composed of market-only relationships (Uzzi 1998). Such networks should be more conducive to the mobilization (Lin 2001) of social capital.

The networked social capital perspective posits that whether or not individuals are able to benefit from their social capital is determined by their own activity and by the willingness of others to share their resources (Lin 2001). Therefore, it is plausible that because of its unique properties, friendship may play an important role in helping scientists to mobilize their social capital for the purposes of productivity. From the network perspective, friendship is an integrative element of social capital. The main mechanisms of this effect are the integration of professional networks and the intensification of interactions within these networks, which then increase the total number of resources mobilized for productivity as well as the efficient use of these resources. Therefore, I posit the following hypothesis:

H3: Scientists with more friends in their professional networks are more productive than scientists with fewer friends.

2.3. Model of the Prevalence and Productivity Effects of Friendship

The model of the prevalence of friendship and its effects on productivity in academic science consists of three sets of constructs (Figure 2-2). The first denotes scientists' human capital and social characteristics. These factors affect what resources scientists can access through their professional networks. The second set of variables denotes elements of social capital: networks of professional relationships, resources scientists have accessed through these networks, and resources that scientists mobilize for the purposes of productivity. The third set of variables denotes a goal, the attainment of which is aided by mobilized resources.

The model posits that friendship is a building block of scientist's social capital. Friendship ties are distinct from other collaborative ties and contain different social capital than other collaborative ties. The prevalence of friendship in personal professional networks varies across groups of scientists, and such variation may be explained by the properties of a scientist's human capital such as the career span, professional leadership, grant-getting expertise, and demographic background. Friendship affects productivity by facilitating the mobilization of all resources, which scientists can access through their personal professional networks for the purposes of productivity. Thus, friendship facilitates the mobilization of both tangible resources, such as information or knowledge, and intangible resources, such as opportunities, shared cognition, trust, and solidarity. Friendship also facilitates the mobilization of network resources for the purposes of productivity by integrating network relationships through the inherent flexibility, the multiplex role structure and homophily, and the trust and solidarity it induces. These properties of friendship may be particularly important for the integration of diverse and sparse networks that span organizational and institutional boundaries, which in the context of science are arguably a source of valued information and knowledge as well as the other knowledge production factors. More importantly, the resource mobilization activities of scientists take place in the context of academic science, which may facilitate or impede these efforts (Fox 1983, Fox and Mohapatra 2007). The model rests on two assumptions about the context of academic science. First, productivity is a positive function of production factors distributed across individuals (Stephan and Levin 1992); and second, scientists invest in their relationships to pool all resources needed to advance scientific knowledge (Bourdieu 1991, Lin 1999).

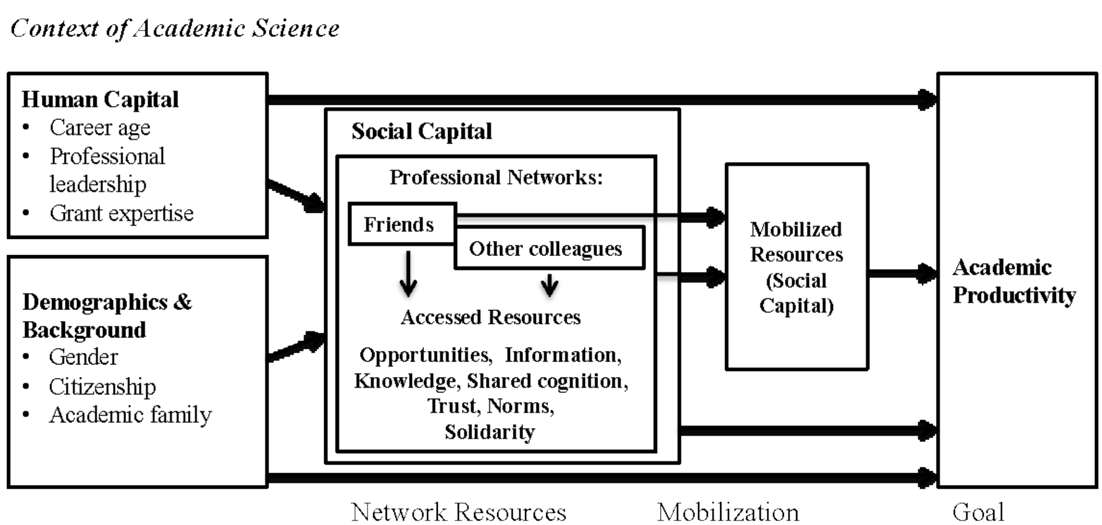

Figure 2-1 Model of the prevalence of friendship and its effects on productivity in the context of academic science

In summary, friendship is an inherent part of the networked social capital of academic scientists. It plays an important role of integration in the mobilization of social capital for productivity purposes. It facilitates the mobilization of social capital by supporting resource mobilization from personal networks and by integrating personal networks, increasing the efficiency of these networks and ultimately leading to higher productivity.

3. DATA, EMPIRICAL MODELS AND ANALYTICAL APPROACH

3.1. Survey and Bibliometric Data Sources

To test the hypotheses set forth in this dissertation, I draw on data from a unique and extensive NSF-funded study of the professional networks of academic scientists in the United States (*NETWISE I: Women in Science and Engineering: Network Access, Participation, and Career Outcomes* (NSF Grant # REC-0529642)). The purpose of this study was to address the following question: How and why do networks matter for women's career outcomes in science and engineering? It is particularly well suited for the research described here because it applies knowledge from social network theory to explore the architecture and dynamics of formal and informal networks which scientists and engineers form, enter, and participate. This study is among the largest national social network studies of academic scientists in the United States, involving two significant data collection components: an extensive national survey of academic scientists and a collection and coding of lifetime bibliometric data for survey respondents. These data are described below.

Survey Data

First, a large-scale national survey involved a two-stage longitudinal (2007-10) survey of academic scientists and engineers in six disciplinary areas who were employed as tenure track faculty in Carnegie Foundation-designated research I universities (150 institutions) (Carnegie Foundation n.d.). The purpose of the study was to examine the structure and resources of the professional networks of academic scientists and to determine the relationship between these factors and a range of career outcomes. An important focus of this study was on how personal networks and their role in careers vary by gender within the academic workforce.

The survey included a range of traditional survey items addressing respondents' individual background, educational background and training, career path and positions held, research, teaching and service responsibilities, grant activities, productivity, job satisfaction, work environment assessment, and other variables that address aspects of the scientists work and work life. A critical aspect of the survey included a detailed section covering the professional networks of these scientists.

To accomplish this, the survey used a detailed egocentric social network design (Wasserman and Faust, 1994) to collect a range of network information about each respondent. These data were then used to provide an extensive second data set on a full range of attributes specific to each respondent's professional network. The study focused on two general sets of professional networks central to the careers of academic scientists: collaborative and advice-based networks. The survey instrument used to collect these data included a series of *name generator* and *name interpreter* questions (Burt and Minor 1983, Wasserman and Faust 1994). Respondents were first asked to write the names of individuals who form their personal professional networks into six name generator questions. Respondents were asked to provide the names of their closest collaborators within the past two years (a) within their home university and (b) outside of their home university. Collaboration was defined as involvement in generating proposals, working on a research project, writing/presenting an academic paper/book or book chapter, or developing industrial products or patents. Another network name generator asked respondents to name individuals with whom "they talk about their research but have never collaborated." Besides collaboration and research discussion networks, which are key to the success of academic scientists, particularly those within the Research I environment, the survey also addressed other career relevant networks. Respondents were asked to name individuals to whom they turn for career-related advice, and individuals with whom they discuss important departmental matters. Finally, respondents were asked if there is someone who they consider to be their primary mentor (and were provided a following mentor definition: "a mentoring relationship is a one-on-one relationship in which a more experienced colleague (a mentor) provides a junior colleague (a mentee) with support, direction, and feedback regarding career-related and other issues. In each of these, respondents were able to name up to five individuals in the collaborative and advice-based name generators and one individual as their primary mentor.

The generation of names was important to not only developing data on network size but also providing a specific relationship in order to gather detailed information on the structure, relational aspects, and resources in the networks. The names that were generated were electronically piped into a series of name interpreter questions in which respondents were asked to indicate whether a range of variables applied to each specific name. Duplicate names were also reduced electronically so that if the same person was named in two or more networks, their name was displayed only one time in the name interpreter section. After respondents of the survey provided names in each of the six name generator questions, they were next presented with a series of name interpreter questions about each of the individuals they had named. Name interpreter questions asked about the types of specific collaboration (e.g., co-authored papers), the types of advice sought from network members, and the types of support provided by network members. Relational questions addressing a range of ways in which individuals were connected to their named network members were also asked.

The relational questions asked through these name generators were the most important to the purposes of this dissertation. A core variable of interest in this dissertation is whether a respondent has one or more friends in their collaborative network. In the survey, a specific name interpreter asked whether the respondent considered the named individual to be a "close friend." The operationalization of friendship as the number of "close friends" is often used in network studies as a measure of relational strength and closeness (Granovetter 1973). While this measurement of friendship is useful for the purposes of this dissertation, the measure has its limitations. First, the name interpreter question that asked if the named individual was a respondent's close friend did not present the parenthetical explanation of the concept, leaving its interpretation to the respondent. Given that friendship is not institutionalized in American society, the perception of friendship may vary across age, gender, ethnicity, and culture (Adams et al. 2000, Keller 2004). Second, the measure is based only on a respondent's perception of friendship with their collaborators. We do not know whether the tie is reciprocal or one directional (Krackhardt 1992). Third, a single measure of the closeness of a friendship limits the analysis to the distinction between relationships that are close friendships and those that are not. It does not allow us to examine the relationship in greater detail or on a scale of closeness, as has been done in some other workplace friendship studies (Dickie 2009, Nielsen et al. 2000). Nevertheless, the operationalization of friendship as a number of "close friends" is a sufficiently robust measure because it (a) limits the range of possible perceptions to the closest friendship ties in the networks of close collaborators, and (b) because the perceived properties of relationships are better predictors of attitudes and trust than actual network ties (Burt 1982, Krackhardt 1987). Other relational data included the age of a relationship, the frequency of interaction, and the origin of an acquaintance. With respect to the similarity between respondents (i.e., alters), the survey asked about the gender and comparative seniority to the respondent as well as the relative closeness of research expertise and comparative grant-securing ability.

The survey was administered online using Sawtooth Software (Sawtooth n.d.). Individuals were invited to the survey via personal email and provided with a unique user ID and password together with information about the study, informed consent language, and the URL for the study website. An invitation was also sent via email to all respondents. Four follow-up reminders were sent at ten-day intervals. Overall, the average time to complete the survey ranged from 30 to 45 minutes.

The sample for this study was developed from a population of roughly 25,000 academic scientists in six disciplinary areas in 150 Carnegie-designated Research I institutions. Six disciplinary areas were selected for this study based on the level of female representation (i.e., low, transitioning, and high). The areas included biological sciences, chemistry, computer science, earth and atmospheric sciences, electrical engineering, and physics. The development of the population was achieved through a web search of academic departments in these disciplines across the Research I institutions. The population data were first stratified by gender, discipline, and rank across the set of 25,000 names. From this stratified set, a final sample of 3,677 names was then drawn randomly.

The first phase survey[3] yielded 1,598 usable responses, which represented an overall response rate of 44%. Responses were evenly distributed across the six fields, gender (48% women), rank (27 % assistant professor, 28 % associate professor, and 45 % full professor) and citizenship, 20% being non-US citizens. The distribution of rank was nearly proportionate to the population with the target sample.

The name generator data yielded 12,727 names ("alters") through the collaborative advice and mentor-based questions. These data were cleaned to remove suspicious or fictional data to the best of our ability. To accomplish this task, we developed a detailed name-cleaning protocol. A team of graduate students then verified each of the 12,727 names and gathered additional information about each of these named individuals, including the employment sector, organizational affiliation, academic rank, gender, and contact information.

The final survey data were divided into two data sets. The primary data set includes all non-network data, and the secondary data set includes the full set of alter-specific data. Alter data were combined (as means, sums, counts, or binary variables, depending on analytical needs and purposes) and merged into the primary data set.

This dissertation uses <u>a selected subset of the survey data, which include data for 1,191 respondents in five academic disciplines</u> (biology (21%), chemistry (21%), computer sciences (19%), earth and atmospheric sciences (23%), and electrical engineering (16%). This subset was generated by the following reduction procedure.

[3] The second survey (not used in this dissertation) was sent to all of the respondents of the first survey. However, it is not discussed here because the follow-on survey data were not used in this dissertation research.

First, the survey yielded a total of 1,598 usable responses, 1,498 (94%) of which provided names of the professional ties of the respondents. Of these, 1,282 (86%) provided the names of their closest collaborators. Individuals who provided information about their professional ties did not significantly differ in terms of their age, gender, or rank from those who did not. However, significantly more U.S. native citizens (mean 0.68 vs. 0.53) provided information about their collaborative ties. Finally, the field of physics was excluded because of the difficulties with the disambiguation of names in the bibliometric data for this field (Wang et al. 2012). The collaborative network was selected for analysis because collaboration in an essential productivity factor (Bozeman et al. 2001, Lee and Bozeman 2005, Stephan and Levin 1992).

Respondents

While the survey asked for general productivity data, full bibliometric data were also collected for each survey respondent. Bibliometric data refers to publication data and reflects academic productivity and knowledge dissemination (De Bellis 2009, Hicks et al 1986). The strength of bibliometric publication data is that it systematically collects, standardizes, and comes from a reputable external data source. The publication data were collected from the Thomson Reuters ISI Web of Science (WoS) Science Citation Index Expanded (Web of Science n.d.) in the summer of 2008 and updated in the summer of 2010. This database annually indexes more than 8,000 major journals across 150 disciplines. To extract data from this database, we developed a detailed bibliometric search protocol that included search by the name, the discipline, and the institutional affiliation of each respondent.

The bibliometric search resulted in a full publication record for each respondent. For cleaning and analysis, the bibliometric data were extracted manually and imported into the data analysis software The Vantage Point (The Vantage Point n.d.). The cleaning of the bibliometric data took place through a name disambiguation and name matching process (Wang et al. 2012), the aim of which was to distinguish the papers of respondents from the papers of homonymous authors. The process involved four steps: filtering the name and affiliation, constructing similarity scores, screening authors, and classifying "boosted trees." The field of physics was excluded from the final data set, because the cleaning of the bibliometric data were complicated by large co-authorship teams, and is therefore it was not possible to ensure its accuracy. Finally, through an additional process, both name interpreter and bibliometric data were checked for additional collection errors. After cleaning, the resulting bibliometric data set included data about peer-reviewed journal articles and conference proceedings published in the journals indexed in the WoS for each survey respondent (except for field of physics). Reviewed conference proceedings are included because of the relative importance of this type of publication for engineering, particularly computer science (Lisee et al. 2008).

Collaborative Networks

The strength of the data source used for this analysis is in the detailed relational data. Because data were collected on specific network relationships, including whether a named individual was a "close friend," the data allow for the detailed analysis presented here. The survey asked respondents to provide the names of their professional ties in two types of name-generator questions: role- and function-based. Respondents were first asked to name up to five individuals, each of whom has, over the past two academic years, been their closest research collaborators (1) within their institution and (2) outside of their institution (including other academic institutions, the government, and industry; and with whom they regularly talk with about research but have never formally collaborated. Next, they were asked to name up to five individuals who served each of the following functions (4) as individuals from whom the respondents had sought advice about their careers or professional development, and (5) as individuals with whom they regularly talk about important university- or department-related issues. Then, the respondents were asked a series of name-interpreter questions about each of the individuals they had named, including if the named individuals were close friends. On average, each respondent named ten professional relationships (mean 9.72). Of these, (1) two collaborators came from within their institution (mean 2.47), (2) three collaborators came from outside of the respondent's institution (mean 2.61), (3) one individual respondents had discussed their research with but had never collaborated with (1.48), (4) two individuals they had turned to for professional developmental advice (mean 1.56), (5) two individuals they regularly talked to about departmental issues (2.22).

Importantly, the three role-based network ties (collaborators within and outside of the university, and individuals the respondents had talked to about their research) are distinct; however, function-based relationships overlap both with the role-based relationships and with one another. Prior work, in which such overlap in personal networks was observed, treated each type of network tie as distinct and consisting of only one function or role (Burt 1997, Bozeman et al. 2001). A number of social network theorists, however, have offered no theoretical or practical reason for treating such multiplex ties as uniplex (Contractor and Monge 2007, Saint-Charles and Mongeau

2009). In this dissertation, I conceptualize the overlap as the multiplexity of relationships.

Thus, the focus of this dissertation is on the networks of respondents' closest collaborators. Networks are comprised of respondents' closest collaborators within and outside of their institutions. These individuals were first named in one of the first two name-generator questions. Then, subsequently, the names of some of these same individuals were also named in the fourth and fifth name generator questions. On average, the respondents reported having a network of close collaborators comprised of 5 ties (mean 5.07, range 1-10) and six roles (mean 6.15, range 1-18). One out of five of these closest collaborators was also a close friend (mean 1.18, range 0-8).

3.2. Empirical models

The purpose of this dissertation is to address the prevalence of friendship and its related effects on academic productivity within the context of academic science. This chapter presents the core models and analytical approach as well as details about the variables included in the analysis. The overall model in this dissertation is depicted in Figure 3-1.

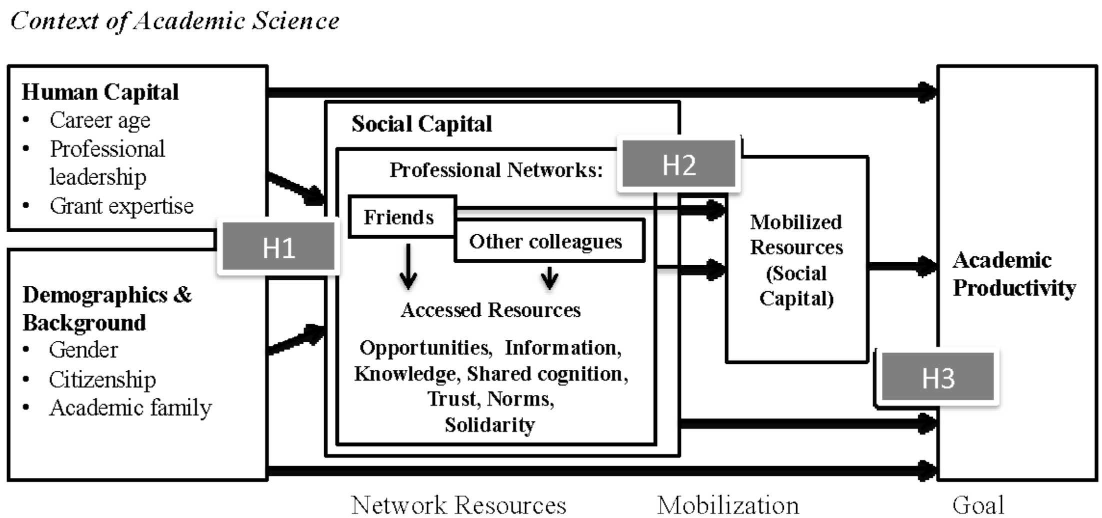

Figure 3-1 The overall model of the prevalence of friendship and its effects on productivity.

To test the hypothesized prevalence of friendship in science and the mechanisms by which it affects scientists' productivity, this section includes a presentation of the three empirical models central to this dissertation research.

1. Model 1: How prevalent is friendship in academic science?

   H1: Senior academic scientists have more friends in their collaborative networks than junior academic scientists.

2. Model 2: How does friendship affect the exchange of resources relevant to productivity in the professional networks of academic scientists?

   H2: Scientists with more friends in their networks mobilize more resources through their networks than scientists with fewer friends.

3. Model 3: How does friendship affect scientist's publication productivity?

   H3: Scientists with more friends in their professional networks are more productive than scientists with fewer friends.

The first model predicts the prevalence of the friendship in academic science (Model 1), the second model the effects of friendship on the intensity of resource mobilization (Model 2), and the third model the effects of friendship on publication productivity (Model 3).

3.2.1. Model 1: Prevalence of friendship in academic science

The first model addresses the question "How prevalent is friendship in academic science?" and tests the factors that predict the existence and prevalence of friendship in the networks of academic scientists. Overall, it aims to examine two aspects of the prevalence: first, whether friendships are present in the personal professional networks of scientists and engineers, and, second, whether some groups of scientists have more friends than others.

Model 1: Friendship = f (seniority, demographic characteristics, context)

Details on the variables included in this model are provided in Table 3-7, and discussed below.

Dependent variables

The dependent variable for this model is friendship, measured in two ways in this dissertation. First, it is measured as a self-reported number of individuals whom respondents consider "close friends" in their collaborative networks. To answer the question of whether friendships exist in the personal professional networks of academic scientists, it is coded as 1 if a respondent considers at least one of the network ties a close friendship, and 0 otherwise (Model 1.1). Second, friendship is also measured as a proportion of the overall collaborative network. To address the question about the variation in number of friends across the group, I coded friendship as the total number individuals whom respondents consider “close friends” (Model 1.2).

Focal independent variables

To test the hypothesized effects of seniority on the existence and the prevalence of friendship in academic science, I included three independent variables of interest and conceptualized seniority as both career age and accomplishments, captured by these three independent variables. The first independent variable is career age, measured as the number of years since respondents were awarded their Ph.D.’s (Long 1992, Lee and Bozeman 2005). The rationale for choosing this measure is that it has been used in the prior empirical work as a proxy for a scientist’s age, rank, and status to avoid a multi-collinearity problem that would emerge if these variables were used in the same model (Lee and Bozeman 2005). In addition, the age of one’s career in science has been linked to the processes of cumulative advantage and cohort effects in science (Long 1992). For testing of the hypothesized relationship between seniority and friendship, one’s career age captures the age, the rank, and the status as well as the dimension of time. Scientists and engineers who have been in academic science for longer times had had more opportunities to meet others similar to them and to develop friendships.

Second, the model includes a number of officer positions in professional associations. This variable captures the effect of being more visible in the science community and belonging to the professional leadership of science (Merton 1973, Mulkay 1976, Zuccala and Van Den Besselaar 2009, Wagner and Leydesdorff 2005). The survey asked respondents to list up to four professional associations in which they were most active; then, they were asked whether they currently hold office positions in these associations.

Third, the model includes the number of grant proposals respondents have submitted as the primary investigator (PI) or co-PI over the previous two years. The rationale for including this variable is that U.S. science is increasingly PI-driven, and the ability to obtain funds, the responsibility of which lies with the PI, is an important aspect of the professional capacity of a scientist (Freeman 2011). The preparation of a research grant application corresponds to the stage in research in which very intensive intellectual exchange takes place and which both relies on and contributes to the formation of strong relationships (Kraut et al. 1987-88, Sonnenwald 2007). Scientists who are more active in preparing grant applications are engaged in more ongoing interactions, and therefore have more opportunities to develop professional relationships, including friendships (Bozeman and Corley 2004).

Other independent variables

While the independent variables above are of primary interest, other variables that account for possible variation across groups are included. More specifically, the reviewed literature suggests that patterns of friendship vary across groups defined by gender (Morrisson 2009, Vigil 2007), status and occupational prestige (Allan 1998, Verbrugge 1977), and culture of origin (Adams et al. 2000, Adams and Plaut 2003, Anderson et al. 2008, Sheets and Lugar 2005, Schug et al. 2009). The literature on cultural psychology suggests that the ways in which people form and maintain their personal relationships differ across cultures. The more individualistic Western cultures are believed to promote voluntary and independent constructions of relationships while more collectivistic cultures promote more embedded interdependent constructions of relationships as an environmental affordance (Anderson et al 2008). In the context of U.S. academic science, the most prevalent demographic divisions are determined by gender and citizenship. According to the National Science Foundation (SEI 2012) in 2008, 29% of all full-time doctoral S&E (science and engineering) research faculty were women, and 27% of the full-time doctoral faculty members were foreign-born (39%–48% in mathematics and engineering). Therefore, the model includes variables that represent these demographic groups of gender and citizenship (native-born U.S. citizens, naturalized U.S. citizens, and foreign born citizens with permanent and temporary visa status). Gender is coded as 1 if a respondent is a woman and 0 otherwise.

The model includes two variables that capture whether familial ties to the academic profession matter in the relationships that scientists develop in their careers. This issue is addressed via parents but also spouses who have had academic careers. Respondents were asked whether either parent was a university professor or whether their spouse held an academic position. The rational for including this variable is based on the notion of academic lifestyle, which necessitates a full commitment to science and excludes non-scientific and personal relationships and activities (Austin 2002, Etzkowitz et al. 1992). Second, Verbrugge (1997) observed that groups in the highest occupational status tend to have friends who are similar to them. Therefore, I infer that scientists of academic origin are likely to have more friends among their professional relationships. Scientists with spouses who are academic scientists may have more friends among their professional ties for several reasons. First, academic couples seek employment in locations where both spouses can work, and many research universities have dual career policies (Wolf-Wendel et al. 2000). Research on dual-career, or "power couples," suggest that couples tend to locate in places where both spouses have employment potential, but singles also tend to move to places where there are others of the same educational level (Compton and Pollak 2007, Costa and Kahn 2000, Shauman and Xie 1996). For scientists, it may indicate that if two scientists relocate together, they may form friendships more within the context of their new workplace, as a primary place of their activities. However, it may also indicate that scientists for whom science is the sole focus of their lives and whose outside-of-the-science interests are limited (Fox 2005) form their friendships primarily around their workplace activities, possibly also meeting spouses in this context. This may be especially true for women, given that more academic woman than men tend to marry fellow scientists (Fox 2005, McNeil and Sher 2001). Thus, it may be the case that the academic lifestyle, which necessitates full commitment to the science and excludes non-scientific and personal relationships and activities, dictates that scientists form their personal relationships, spousal and friendship, in the context of their workplace (Austin 2002, Etzkowitz et al. 1992, Fox 2005). Moreover, the achievement or failure of dual-career arrangements is considered a social-relational process in such a way that partners' lives are embedded with and influenced by each other (Rusconi and Solga 2008). It is likely that such embeddedness is also reflected in the higher number of workplace friendships because scientists who are married to other scientists consolidate their work roles and pool their friendships.

Finally, the workplace literature suggests that some professional contexts facilitate friendship more than others (Riordan and Griffeth 1995, Tse et al. 2008). Therefore, the model includes a variable that captures the size of the respondent's department and a set of binary variables that captures the effects of the respondent's scientific discipline. The rational for including the size of department is the idea that larger departments afford a larger pool of potential friendship ties. Regarding the discipline, fields of science differ in the nature of their knowledge production, workforce structure, and collaboration patterns. For example, Bozeman and Lee (2005) observed a significant variation in the number of collaborators across scientific disciplines. Similarly, the fields of computer science and electrical engineering are more international in terms of their workforce composition than other fields in the sample (Melkers and Kiopa 2010, National Science Board 2008), which may have an effect on both the network composition and friendship because of the availability of similar individuals (Bukowski and Newcomb 1984, Ibarra 1997, McPherson et al.2001).

Table 3-1 provides basic descriptive statistics for the variables included in the model. Table 3-2 provides pairwise correlations for Model 1. Of the 1,191 academic scientists and engineers, 46% are women, 68% are native-born U.S. citizens, 17% originate from an academic family (one or more faculty parent), and 26% have an academic spouse. More than a half of respondents (53%) have at least one close friend among their closest collaborators. The number of friends in the network of closest collaborators ranges from 0 to 8, and the mean number of friends is 1.17 (standard deviation 1.53). The strongest positive bivariate correlation with friendship can be observed for the variable that depicts whether a respondent has an academic spouse: the correlation is .15 with a binary variable depicting the presence of friendship and .12 for the number of friends.

Logit and negative binomial model of the prevalence of friendship

Given the structure of the data and the binary and count-dependent variables, the prevalence of friendship will be analyzed using logit and negative binomial estimation (Long and Freese 2006). The logit model will be used to estimate the effects of the independent variables on the probability of having at least one friend. The logit estimation is the most appropriate in this case because the dependent variable is binary. The negative binomial model will be used to estimate the effects of the independent variables on the number of close friends among the closest collaborators. Negative binomial estimation is the most appropriate in this case because the dependent variable, count of friends, is overdispersed, and it fits the data better than the Poisson, which would be an alternative option for this type of data (Long and Freese 2006, Karazsia and Van Dulmen 2008).

Table 3-1 Descriptive statistics: Model of the prevalence of friendship in academic science (Model 1)

	Obs.	Mean	Std. Dev.	Min	Max
Dependent variable: Friendship					
Close collaborator is a friend (0,1)	1191	.53	.50	0	1
Number of friends	1191	1.17	1.53	0	8
Independent variables: Seniority and accomplishments in the science community					
Career age	1187	18.34	1.35	1	54
Number of offices in professional associations	1191	.24	.52	0	3
Number of grant proposals	1156	7.99	11.25	0	200
Demographics					
Gender	1191	.46	.50	0	1
U.S. citizen (native-born)	1191	.68	.47	0	1
U.S. citizen (naturalized)	1191	.13	.34	0	1
Foreign citizen	1191	.19	.39	0	1
Academic Family					
Academic family background	1191	.17	.37	0	1
Academic spouse	1191	.26	.44	0	1
Discipline and Department					
Department size	1191	35.91	29.07	1	177
Biology	1191	.21	.41	0	1
Chemistry	1191	.21	.41	0	1
Computer science	1191	.19	.39	0	1
Earth and atmospheric sciences	1191	.24	.42	0	1
Electrical engineering	1191	.16	.36	0	1

Table 3-2 Pairwise correlations: Model of the prevalence of friendship in academic science (Model 1)

	Close collaborator is a friend (0,1)	Number of friends	Career age	Number of offices	Number of grant proposals	Gender	U.S. citizen (native-born)	U.S. citizen (naturalized)	Foreign citizen	One or both parents are faculty
Close collaborator is a friend (0,1)	1									
Number of friends	.73*	1								
Career age	-.07*	-.02	1							
Number of offices in professional associations	.08*	.11*	.04	1						
Number of grant proposals	.05	.12*	-.06	.07*	1					
Gender	.08*	.02	-.06*	.15*	-.05	1				
U.S. citizen (native-born)	.09*	.11*	.21*	.01	-.05	.09*	1			
U.S. citizen (naturalized)	-.02	-.05	.10*	-.01	.05	-.02	-.57*	1		
Foreign citizen	-.08*	-.08*	-.33*	-.01	.02	-.09*	-.69*	-.19*	1	
One or both parents are faculty	-.02	-.02	-.09*	.04	.00	.03	.04	-.03	-.02	1
Partner is faculty	.15*	.12*	-.01	.03	-.01	.26*	-.01	.01	.00	.10*
Department size	.02	-.01	.04	.01	.00	.01	-.02	.03	.01	.00
Biology	.02	.03	.11*	-.04	-.04	-.01	.12*	-.04	-.10*	-.05
Chemistry	-.03	-.10*	.04	-.04	.01	.03	.05	-.06*	.00	.00
Computer science	-.03	-.04	-.06*	-.05	-.02	-.01	-.11*	.07*	.07*	.04

Table 3-2 continued

Earth and atmospheric sciences	.09*	.18*	.02	.03	.02	.02	.13*	-.07*	-.09*	-.01
Electrical engineering	-.06	-.09*	-.13*	.11*	.03	-.03	-.22*	.14*	.14*	.03

	Partner is faculty	Department size	Biology	Chemistry	Computer science	Earth and atmospheric sciences	Electrical engineering
U.S. citizen (naturalized)							
Foreign citizen							
One or both parents are faculty							
Partner is faculty	1						
Department size	-.01	1					
Biology	.06*	.08*	1				
Chemistry	-.06	-.08*	-.26*	1			
Computer science	-.01	.18*	-.25*	-.25*	1		
Earth and atmospheric sciences	.01	-.20*	-.29*	-.29*	-.27*	1	
Electrical engineering	-.01	.05	-.22*	-.22*	-.21*	-.24*	1

Legend: * p<.05

3.2.2. Effects of friendship on resource mobilization

The second empirical model addresses the research question "How does friendship affect the exchange of resources relevant to productivity in the professional networks of academic scientists?" It aims to explain the mechanisms by which friendship affects the mobilization of resources from personal professional networks.

Model 2: Mobilized resources=f(friendship, network properties, demographic characteristics, and context)

Details on the variables included in this model are provided in Table 3-7 and discussed below.

Dependent variable

The dependent variable for this model depicts resources that scientists mobilize from their networks. It is constructed as a summation of five resource items based on the name interpreter data. Respondents were asked whether they had mobilized five types of productivity-relevant resources from their collaborators such as a practical know-how and knowledge related to a scientist's work (revisions of papers and grant proposals that they were not coauthoring), collaboration opportunities (introductions to collaborators outside of the respondent's own university), endorsements of reputation (nominations for awards or as invited speakers), and joint work on grant proposals and co-authorship (collaboration on a journal paper or a book chapter). If a respondent indicated that they had interacted with their named collaborator in these ways, their positive answer was coded as 1. The resulting scale measures the construct of mobilized network resources with a Cronbach's Alpha of .73. Based on DeVellis (2011) and others, this value indicates that the scale is internally consistent and therefore reliable.

Independent variable

The independent variable in the model is friendship. It is measured the same as above in Model 1.2: as the number of self-reported friendships in the network. The model chooses the number of friends over the binary measure of indicating a presence of friendship because in the context of resource mobilization, the size of the network is important because larger friendship networks may be a source of more resources (Campbell et al. 1986).

Other Independent variables

While friendship is the focal independent variable of interest, variables that account for the possible effects of accessed resources and their variation across different groups of scientists are also included. One depicts the size of a scientist's collaborative network. Network size is included because the more relationships an individual has, the greater the chance that this individual possesses the needed resource (Burt 1983, Borgatti et al. 1998). The second set of variables includes demographic characteristics and context: gender, citizenship, career age, and science discipline. All of the variables in this set are operationalized the same as in the first model. The rationale for including these variables is to control for variations in the patterns of resource mobilization across the demographic groups and stages of careers as well as the norms and structure of the respective discipline. The rationale for including demographic characteristics in this model is to account for unobserved factors that effect a scientist's behavior and interaction experiences within these groups (McPherson et al. 2001, Mao 2006, Mao et al. 2009, Morrisson 2009, Vigil et al. 2007) and disciplines (Becher and Trowler 1989, Knorr Cetina 1999, Lamba and Mace 2011).

Table 3-3 presents descriptive statistics for the variables included in Model 2; Table 3-4 presents pairwise correlations for Model 2. On average, respondents mobilize about 8 resources (mean 7.71), which include reviews of grant-proposals and papers on which collaborators are not coauthors, introductions to potential collaborators outside of the university, reputation endorsements by nominations of an invited speaker or an award, collaborations on grant proposals, and co-authorship. The statistics show a significant positive correlation between friendship and the total number of mobilized resources (.51).

Negative binomial model of resource mobilization

As stated above, given the count-dependent variable, the effects of friendship for resource mobilization will be analyzed by negative binomial estimation (Long and Freese 2006), which is most appropriate in this case because the dependent variable, the count of resources, is overdispersed, and it fits the data better than the Poisson, which would be alternative option for this type of data (Long and Freese 2006, Karazsia and Van Dulmen 2008).

Table 3-3 Descriptive statistics: Model of the effects of friendship on resource mobilization (Model 2)

	Obs.	Mean	Std. Dev.	Min	Max
Dependent variable: Mobilized resources					
Mobilized Resources	1191	7.72	6.24	0	31
Independent variable: Friendship					
Number of friends	1191	1.17	1.53	0	8
Network properties					
Network size	1191	5.07	2.46	1	10
Demographics					
Gender	1191	.46	.50	0	1
U.S. citizen (native-born)	1191	.26	.44	0	1
U.S. citizen (naturalized)	1191	.29	.45	0	1
Foreign citizen	1191	.46	.50	0	1
Career age and discipline					
Career age	1187	18.34	1.35	1	54
Biology	1191	.21	.41	0	1
Chemistry	1191	.21	.41	0	1
Computer science	1191	.19	.39	0	1
Earth and atmospheric sciences	1191	.24	.42	0	1
Electrical engineering	1191	.16	.36	0	1

Table 3-4 Pairwise correlations: Model of friendship effects for the resource mobilization (Model 2)

	Resources	Friendship	Network size	Gender	U.S. citizen (native-born)	U.S. citizen (naturalized)	Foreign citizen	Career age	Biology	Chemistry
Resources	1									
Friendship	.51*	1								
Network size	.62*	.39*	1							
Gender	.05	.02	.07*	1						
U.S. citizen (native-born)	.05	.11*	.04	.09*	1					
U.S. citizen (naturalized)	-.02	-.05	-.07*	-.02	-.57*	1				
Foreign citizen	-.03	-.08*	.01	-.09*	-.69*	-.19*	1			
Career age	-.14*	-.02	-.13*	-.06*	.21*	.10*	-.33*	1		
Biology	-.02	.03	-.08*	-.01	.12*	-.04	-.10*	.11*	1	
Chemistry	-.05	-.10*	-.12*	.03	.05	-.06*	.00	.04	-.27*	1
Computer science	-.02	-.04	.03	-.01	-.10*	.07*	.07*	-.06*	-.25*	-.25*
Earth and atmospheric sciences	.14*	.18*	.15*	.02	.13*	-.07*	-.09*	.02	-.29*	-.29*
Electrical engineering	-.05	-.09*	.02	-.03	-.22*	.14*	.14*	-.13*	-.22*	-.22*
	Computer science	Earth and atmospheric sciences	Electrical engineering							
Chemistry										
Computer science	1									
Earth and atmospheric sciences	-.27*	1								
Electrical engineering	-.21*	-.24*	1							
Legend: * p<.05										

3.2.3. Effects of friendship on productivity

The empirical model addresses the research question "How does friendship affect scientist's publication productivity?" It aims to explain the mechanisms by which friendship affects the productivity of academic scientists and engineers.

Model 3: Productivity = f (friendship, network characteristics, demographic characteristics, and context)

Details on the variables included in this model are provided in Table 3-7 and discussed below.

Dependent variables: Productivity

The dependent variable in this model is publication productivity, measured as the count of peer-reviewed journal publications over a three-year period from 2007 to 2009 (Model 3.1) and an average fractional count of publications over a two-year period from 2007 to 2009 (Model 3.2).

Publication count and fractional count are two of the most frequently used bibliometric proxy measures of scientific productivity (Bozeman and Lee 2005, among others). Given that scientific publications are increasingly coauthored (NSB 2011, O'Brien 2011, among others), simple publication count can be considered a measure of collaborative productivity (Garner et al. 2012). The fractional count, in turn, can be seen as personal productivity because it measures a fraction of publication and thus reflects the contribution of each coauthor. The bibliometric literature points to several issues related to assigning authorship: that not all authors contribute to a publication equally and that it is not uncommon in the scientific community to grant authorship for purely social reasons (Kraut et al. 1987-88, LaFollette 1992). Therefore, use of multiple measures is preferable over the use of a single measure (De Bellis 2009). Both counts are taken over a three-year time period (Levin and Stephan 1992, Long 1978, Fox and Faver 1985), which is more beneficial to has an advantage over the publication counts for time periods (i.e., one year) because in that it accounts for the effects of life events that might facilitate or impede publication in during a given year (Fox and Faver 1985). The period from 2007 to 2009 was selected because the survey was conducted in the winter of 2006-07 (November-January).

Independent variable: Friendship

The independent variable in this model is friendship, measured as before, as the total number of friends in a network.

Other independent variables

This study includes other variables that account for effects of mobilized resources and other productivity-relevant aspects of social capital, the variation in productivity across demographic groups of scientists, and the specifics of the discipline of science. The first set of variables captures the effects of social capital. They include the network size, mobilized resources, and the EI-index. As discussed in Chapter 2, to benefit from social capital, individuals must actively use it (Bozeman et al. 2001, Lin 2001). The size of a personal collaborative network is a primary measure of social capital: larger networks allow access to more resources. Several empirical studies have found that collaboration affects publication productivity (Duque et al. 2005, Fox and Mohapatra 2007, Lee and Bozeman 2005, Shrum 2007). Two subsequent variables that capture the effects of resources that respondents mobilize from their networks are measured the same as they were in Model 2. The control variable, the proportional EI-index, captures the external orientation of the collaboration network (Krackhardt and Stern 1988). The index is calculated as

$$\boldsymbol{EI - index = \frac{E-I}{E+I}},$$

where E=the number of collaborators outside of a respondent's university, and I=the number of collaborators within the respondent's university. In the context of productivity, as a source of non-redundant information, external ties may affect productivity and allow scientists to access knowledge production factors that they do not have themselves (Beaver 2001, Fox and Mohapatra, 2007, Katz and Martin 1997, Lee and Bozeman 2005, McFadyen et al. 2009, Singh 2000, Oh et al. 2006).

In addition to social capital variables, the model includes a variable that captures the effect of the respondent's research grants. Measured as the number of graduate students currently supported by the respondent's research grants, it accounts for variation in grant size across science disciplines (Melkers and Kiopa 2010).

The model also includes several demographic characteristics that may account for variation in productivity in the model. The set of demographic characteristics and context variables includes gender, citizenship, and the age of the career, and the discipline of science. The rationale for including gender is related to the observation of science studies that publication productivity varies by gender (Cole and Cole 1973, Fox 1983, Larivivière et al. 2011, Levin and Stephan 1991, Long 2001, Smith-Doerr 2004, Whittington and Smith-Doer 2005). Furthermore, empirical research has documented that foreign citizens are more productive that U.S. citizens (Bozeman and Corley 2004). As noted above, the age of one's career is a single measure that captures the effect of the scientist's age, rank, and status (Lee and Bozeman 2005). Empirical research also suggests that each of these three factors affects productivity (Bland et al. 2005, Lee and Bozeman 2005, Levin and Stephan 1991, Xie and Shauman 2003). Lastly, the discipline of science, which accounts for the productivity patterns of the discipline, is included. All of the variables in this set are measured the same as they are above (Model 2). Table 3-5 presents descriptive statistics for the variables included in Model 3; Table 3-6 presents pairwise correlations for Model 3. On average, respondents have about 7 publications (mean 6.86, range 0-71) in the journals indexed in the ISI Web of Science. While friendship does not correlate significantly with the publication count or fractional publication count, mobilized resources have a positive and significant correlation with the two publication counts (.26 and .17).

Recursive negative binomial and ordinary least squares models of productivity

To understand how friendship affects publication productivity, negative binomial and ordinary least square regression models will be used. As stated above, negative binomial estimation is the most appropriate estimation for publication count because the count of publications is overdispersed, and it fits the data better than the Poisson, which would be alternative option for this type of data (Long and Freese 2006, Be Bellis 2009, Ynalvez and Shrum 2011). The OLS regression is the most appropriate estimation method for the fractional publication count, which is a continuous variable (Lee and Bozeman 2005).

In this model, the number of friends in a collaborative network represents friendship. A number of individual level factors, both observed and unobserved, determines the number of friends among the closest collaborators. Given that these factors may also influence scientists' publication productivity, the error terms for Models

1 and 3 may be correlated, which imposes a problem of biased and inconsistent estimators (Wooldridge 2009). To treat this problem, empirical studies have suggested several recursive-modeling techniques (Hartman 1988, Khanna and Damon 1999, Lee and Trost 1978, Welch et al. 2000). First, studies have addressed this problem by using an instrumental variable correlated with the problematic variable and uncorrelated with the error term (Wooldridge 2009). Given that friendship is a focal variable of interest, this approach is not appropriate for these purposes. Therefore, I use a two-stage technique that first explains the endogenous variable using a probabilistic choice model (the first stage), and then incorporate the predicted probabilities into the model that analyzes the relationships of interest (the second stage). This approach is typically used in studies that model the effects of individual behavior on some kind of performance outcomes and need to correct for the self-selection bias (Lee and Trost 1978, Khanna and Damon 1999, Welch et al. 2000).[4] Accordingly, I analyze the effects of friendship on publication productivity from 2007 to 2009 (Model M3) using the predicted values of the number of friends from Model 1, which examined the variation of the prevalence of friendship across different groups of scientists.

[4] For example, Welch et al. (2000) used such a two-stage technique to model the effects of the voluntary decisions of firms that participated in an environmental program to change their carbon emissions over time. The authors reasoned that the observable decision to participate in a voluntary program is a proxy of the unobserved voluntarism, which affects both the decision to participate in the program and the performance outcome–the reduction of carbon emissions. Therefore, to model the performance effects of voluntarism, these authors used a probabilistic choice method to obtain estimates of the endogenous predictor–a decision to participate in the program (Stage 1), and then they used an OLS model with predicted values obtained from the first stage model as the independent variable in the second stage model, which linked this decision to the reduction in emissions (Stage 2).

Table 3-5 Descriptive statistics: Model of the effect of friendship on publication productivity (Model 3)

	Obs.	Mean	Std. Dev.	Min	Max
Dependent variable: Productivity					
Publication count 2007-09	1028	6.86	7.10	0	71
Fractional publication count	937	2.21	2.05	0	18.57
Independent variable: Friendship					
Number of friends	1191	1.17	1.53	0	8
Network properties					
Network size	1191	5.07	2.46	1	10
EI-Index	1191	.00	.53	-1	1
Mobilized Resources	1191	7.72	6.24	0	31
Number of graduate students	1177	2.19	2.52	0	20
Demographics and discipline					
Gender	1191	.46	.50	0	1
U.S. citizen (native-born)	1191	.68	.47	0	1
U.S. citizen (naturalized)	1191	.13	.34	0	1
Foreign citizen	1191	.19	.39	0	1
Career age	1187	18.34	1.35	1	54
Biology	1191	.21	.41	0	1
Chemistry	1191	.21	.41	0	1
Computer science	1191	.19	.39	0	1
Earth and atmospheric sciences	1191	.24	.42	0	1
Electrical engineering	1191	.16	.36	0	1

Table 3-6 Pairwise correlations: Model of friendship effect of the publication productivity (Model 3)

	Publication count 2007-09	Fractional publication count	Friendship	Network size	EI-Index	Resources	Number of graduate students	Gender	U.S. citizen (native-born)
Publication count 2007-09	1.00								
Fractional publication count	.90*	1.00							
Friendship	.05	-.01	1.00						
Network size	.20*	.11*	.39*	1.00					
EI-Index	.10*	.06	.06*	.10*	1.00				
Mobilized Resources	.26*	.17*	.51*	.62*	.09*	1.00			
Number of graduate students	.44*	.42*	.01	.21*	-.06*	.15*	1.00		
Gender	-.04	-.07*	.02	.07*	.10*	.05	.02	1.00	
U.S. citizen (native-born)	-.08*	-.08*	.11*	.04	-.02	.05	-.04	-.03	1.00
U.S. citizen (naturalized)	.00	-.01	-.05	-.07*	.00	-.02	.05	.03	-.02
Foreign citizen	.09*	.11*	-.08*	.01	.02	-.03	.00	.01	-.09*
Career age	-.04	-.05	-.02	-.13*	-.02	-.14*	-.03	.11*	-.06*
Biology	.00	-.06	.03	-.08*	.07*	-.02	-.12*	-.01	-.01
Chemistry	.15*	.15*	-.10*	-.12*	-.11*	-.05	.15*	.17*	.03
Computer science	-.22*	-.17*	-.04	.03	-.11*	-.02	.05	-.14*	-.01
Earth and atmospheric sciences	.01	-.01	.18*	.15*	.20*	.13*	-.19*	-.03	.02
Electrical engineering	.05	.09*	-.09*	.02	-.06*	-.05	.14*	.01	-.03

	U.S. citizen (native-born)	U.S. citizen (naturalized)	Foreign citizen	Career age	Biology	Chemistry	Computer science	Earth and atmospheri c sciences	Electrical engineering
U.S. citizen (naturalized)	1.00								

Table 3-6 continued

Foreign citizen	-.69*	1.00						
Career age	.20*	.10*	1.00					
Biology	.12*	-.04	-.09*	1.00				
Chemistry	.05	-.06*	.00	.04	1.00			
Computer science	-.10*	.07*	.07*	-.06*	-.25*	1.00		
Earth and atmospheric sciences	.13*	-.07*	-.09*	.02	-.28*	-.27*	1.00	
Electrical engineering	-.22*	.14*	.14*	-.13*	-.22*	-.21*	-.24*	1.00

Legend: * p<.05

Table 3-7 Summary of variables

Concept	Operationalization	Measurement	Model
Dependent Variables:			
Friendship			
Friendship	Presence of friendship in the network	[0/1] A self reported number of individuals whom respondents consider “close friends”, coded as 1 if respondent considers at least one of the network ties close friendship, 0 otherwise	1
	Number of friends in the network	[N] Total number relationships, which respondents consider “close friends” in their collaboration network within and outside of the university	1
Mobilized Resources			
Mobilized resources	Total of resources respondents mobilize from networks	[N] Sum of reviews, introductions, nominations, collaborations on grant proposals, and co-authorship respondent mobilized from network	1
Mobilized resources	Sum of co-authorship respondents mobilize from networks	[N] Sum of co-authorship respondent mobilized from network	1
Productivity			
Collaborative publication productivity	Count of peer-reviewed journal publications over period of three years from 2007 to 2009	[N] Count of publications in the journals indexed in WoS	3
Personal publication productivity	Fractional count peer-reviewed journal publications over period of three years from 2007 to 2009	[N] Fractional count of publications in the journals indexed in WoS	3
Independent Variables:			
Friendship			
Friendship	Number of friends in the network	[N] Total number relationships, which respondents consider “close friends” in their collaboration network within and outside of the university	2
		[N-hat] Predicted number of relationships, which respondents consider “close friends” in their collaboration network within and outside of the university	3
Seniority and accomplishments in the science community			
Career age	Years since Ph.D.	[N] Number of years since Ph.D.	1
Professional leadership	Chairing professional associations	[N] Sum of chaired positions. The survey asked respondents to name associations in which they are members, and to indicate whether they currently hold chaired position in the named association.	1

Grant expertise	Number of grant proposals	[N] Number of grant proposals have submitted as PI or co-PI over past two years	1

Table 3-7 continued

Other Independent Variables:

Network Properties			
Network Size	Number of ties in network	[N] Number of ties	2, 3
External orientation of network	E-I index	[(-1)-(+1)] (E-I)/(E+I), where E=number of collaborators outside of respondent's university, I=number of collaborators within respondent's university	3
Mobilized resources	Sum of resources respondents mobilize from networks	[N] Sum of reviews, introductions, nominations, collaborations on grant proposals, and co-authorship respondent mobilized from network	3
Mobilized resources	Sum of co-authorship respondents mobilize from networks	[N] Sum of co-authorship respondent mobilized from network	3
Grant Resources			
Research grant resources	Number of graduate students that are currently supported by the respondent on a research grant	[N] Self reported number of graduate students	3
Demographic Characteristics and Context			
Gender	Gender of respondent	[0/1] Gender, coded as 1 for women, 0 for men	1, 2, 3
Citizenship	Respondent's citizenship	[0/1] Citizenship, coded for each group of self reported citizenship: U.S. native born, U.S. naturalized, and foreign citizens	1, 2, 3
Academic family	One or both of respondents' parents are a faculty member in a university or college	[0/1] 1 if parents are faculty members, 0 otherwise	1
Academic spouse	Has a partner who is a faculty member in a university or college	[0/1] 1 if partner is a faculty member, 0 otherwise	1
Career age	Years since Ph.D.	[N] Number of years since Ph.D.	2, 3
Department size	Department size	[N] Number of faculty in respondent's department	1
Discipline	Science discipline	[0/1] coded as 1 for each discipline chemistry, computer sciences, earth and atmospheric sciences, and electrical engineering	1, 2, 3

4. RESULTS

This chapter presents the descriptive and statistical results of the analysis. It is organized in three sections. The first addresses the question of the prevalence of friendship in academic science. It presents the descriptive results of the comparison of friendship to other collaborative ties and offers a comparison of the accessed social capital of the respondents. The results of the core two explanatory models, which address the factors that may explain the prevalence of friendship in academic science, are also presented. The second section addresses the question of how friendship affects resource mobilization from personal collaborative networks. This section begins by presenting the descriptive results that compare the resources that scientists mobilize from their friends and other collaborators and follows with a presentation of the results from the explanatory models that test the hypothesized effects of friendship on resource mobilization. The final section of this chapter addresses the question of how friendship may affect the publication productivity of academic scientists and engineers. This section also presents the results of the core explanatory model that tests the hypothesized effects of friendship on collaborative and personal publication productivity. The chapter concludes with an overall summary of the findings.

4.1. Prevalence of Friendship in Academic Science

To answer the first research question of this dissertation, "How prevalent is friendship in academic science," I first examine whether friendship is present among the collaborative ties of faculty and how tie-level data show that friendships differ from other collaborative ties. I examine whether the two types of ties differ with regard to homophily and heterophily, and the origination and structure of relationships, and then analyze the differences between the accessed social capital (conceived as the properties of the collaborative network) of scientists who have friends and those who do not. Finally, I present the results of empirical models that test hypothesized relationships between those with seniority in the science community and the prevalence of friendship among scientist's closest collaborative ties.

4.1.1. Descriptive results

The reviewed literature suggests that friendship is not uncommon among workplace relationships (Dickie 2009, Lee and Ok 2011, Mao 2006, 2009, Morrison 2004, Song and Olshfski 2008, Tse et al. 2008). The baseline proposition *(P1)* of this dissertation states the following: *Friendship is present among the relationships in the professional networks of academic scientists*. The descriptive results support this proposition: 54% of respondents consider at least one of their closest collaborators to also be a close friend (Table 4-1). The results of a t-test show that the most "friendly" science discipline is the field of earth and atmospheric sciences, in which 61% of respondents say that at least one of their collaborators is a close friend ($Pr|T| > |t|=.003$).

Table 4-1 Prevalence of friendship: Respondents who have at least one friend among their collaborative ties

	N	Mean
All disciplines	**1191**	**.54**
Biology	248	.55
Chemistry	249	.50
Computer science	227	.50
Earth and atmospheric sciences	281	.61**
Electrical engineering	187	.47
Legend: * p<.05; ** p<.01; ***p<.001		

Friendship vs. other collaborative ties

According to the reviewed literature, a distinct property of friendship that is particularly important in the context of the mobilization of social capital is its inherent flexibility. The inherent flexibility of friendship has two aspects. First, it implies normative flexibility, which allows for the bridging of differences and the integration of social structures (Anderson 2001, Blatterer 2010, Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008, Merton and Lazarsfeld 1954). Second, it implies adaptability to changing contexts (Hruschka 2010, Conradson and Lathan 2005). The first indicator of the normative flexibility of friendship is its ability to accommodate diversity (Krackhardt and Kilduff 1990, Rezende 1999), which reflects the extent to which friendship, compared to other collaborative ties, is heterophilous, or the opposite, homophilous (Lazarsfeld and Merton 1954, Verbrugge 1977, McPherson). The analysis of the tie dataset allows the examination of several aspects of similarities/differences that are important in the context of social interactions and productivity in science: status, funding, and gender similarity or difference. The social capital literature suggests that dissimilar relationships and/or more resourceful relationships than others may provide access to valuable and non-redundant resources (Burt 1992, Lin 2001, Flap and Volker 2001). At the same time, those who are more resourceful consider it important to maintain their resources (Lin 2001, Verbrugge 1977). Tables 4-2, 4-3, and 4-4 report the results of a one-way ANOVA test for status and funding heterophily and gender homophily between friendships and other collaborative relationships. The status and funding heterophily is coded as (-1) if an alter is junior to a respondent or if a respondent considers an alter's ability to get funding worse than his/her own; (0) if an alter has equal seniority and grant-securing ability; and (+1) if an alter is senior to respondent or of higher grant-securing ability. Thus, a positive mean value of status and funding homophily indicates that respondents are connected with individuals whom they consider senior or individuals they consider more capable than themselves; a negative mean value indicates that respondents are connected with junior or lower capability individuals, and 0 means that they are connected to equal individuals (Tables 4-2 and 4-3). Gender homophily is coded (1) if the gender of a respondent and an alter is the same, and 0 if different. A positive non-zero mean value indicates gender homophily, and 0 – heterophily (Table 4-4).

It appears that friendships of U.S. scientists and engineers form primarily <u>within status groups</u>, and not across them. Friendships are more homophilous by all three homophily counts: status (mean heterophily .07 for friends vs. .14 for others), funding (mean heterophily .14 for friends vs. .20 for others) and gender (mean homophily .61 for friends vs. .54 for others). The lower score of status and funding heterophily for friends compared to that of other relationships suggests that friendships exist between more similar individuals whereas other collaborative relationships exist between more dissimilar people. Interestingly, both perceived status and funding heterophily is positive, which suggests that it is upwardly biased; respondents on average consider their collaborators as being of higher, not lower status and better grant-getters than themselves. While this finding, in part, may reflect respondents' consideration and respect towards their collaborators, it may also reflect the tendency of people in middle and high prestige occupations to connect with those of higher status (Verbrugge 1977). It may also reflect the primary social divisions within the academic community, which has been described as inherently hierarchical (Bourdieu 1990, Fox 2006)

A considerable variation in the three homophily accounts can be observed across the groups of respondents defined by rank, gender, and citizenship. The friendships of assistant professors are characterized by greater status and funding homophily than their other collaborative relationships (mean status heterophily .38 vs. .61; mean funding heterophily .38 vs. .61). The friendships of full and associate professors, however, are characterized by greater gender homophily. Similarly, friendships of men are characterized by greater status and funding homophily than their other relationships, whereas the friendships of women are characterized by higher gender homophily than their other relationships. This finding may be explained by an assertion from social psychology that members of so-called "edge" groups, such as high status or minority groups tend to form more homophilous relationships (Verbrugge 1977). One explanation for this phenomenon is that individuals with rare properties tend to be treated differently (i.e., they are valued, envied, or discriminated against) by the majority, so they form a special bonds and solidarity with one another. By citizenship, friendships of native-born U.S. citizens are characterized by greater gender homophily than other collaborative relationships, but friendships of naturalized U.S. citizens and foreign citizens are no more or less gender homophilous than other collaborative ties. However, for status and funding heterophily, standard deviations are high (.75 for status heterophily and .68 for funding), which suggests considerable variation across individuals. Such individual variation is smaller and thus more consistent for gender homophily.

Table 4-2 Status heterophily: Difference in means for friendships vs. other collaborative ties

	Mean	**Std. Dev.**	**Min**	**Max**	**Mean**	**Mean**
	All N=6039				**Not Friend N=4640**	**Friend N=1399**
All respondents	**.12**	**.75**	**-1**	**1**	**.14**	**.07****
Within demographic groups						
Assistant professor	.56	.61	-1	1	.61	.38***
Associate professor	.20	.72	-1	1	.21	.17
Full professor	-.17	.68	-1	1	-.18	-.14
Men	.09	.74	-1	1	.11	.00***
Women	.16	.74	-1	1	.16	.16
Native born U.S. citizen	.08	.10	-1	1	.10	.05*
Naturalized U.S. citizen	-.02	.74	-1	1	.74	.71
Foreign citizen, permanent visa	.28	.72	-1	1	.30	.20
Foreign citizen, temporary visa	.61	.59	-1	1	.65	.37*
Legend: * p<.05; ** p<.01; ***p<.001						

Table 4-3 Funding heterophily: Difference in means for friendships vs. other collaborative ties

	Mean	**Std. Dev.**	**Min**	**Max**	**Mean**	**Mean**
	All N=5109				**Not Friend N=4510**	**Friend N=1652**
All respondents	**.18**	**.68**	**-1**	**1**	**.20**	**.14****
Within demographic group						
Assistant professor	.56	.61	-1	1	.61	.38***
Associate professor	.19	.68	-1	1	.19	.20
Full professor	-.17	.68	-1	1	-.18	-.14
Men	.09	.74	-1	1	.11	.00*
Women	.16	.74	-1	1	.16	.16
Native born U.S. citizen	.08	.73	-1	1	.10	.05*
Naturalized U.S. citizen	.09	.68	-1	1	.07	.16
Foreign citizen, permanent visa	.23	.66	-1	1	.25	.15
Foreign citizen, temporary visa	.38	.61	-1	1	.41	.17*
Legend: * p<.05; ** p<.01; ***p<.001						

Table 4-4 Gender homophily: Difference in means for friendships vs. other collaborative ties

N=6039	Mean	Std. Dev.	Min	Max	Mean	Mean
	All N=6039				Not Friend N=4640	Friend N=1399
All respondents	**.56**	**.50**	**0**	**1**	**.55**	**.61*****
Within demographic group						
Assistant professor	.57	.50	0	1	.58	.55
Associate professor	.56	.50	0	1	.52	.66***
Full professor	.56	.50	0	1	.55	.60**
Men	.85	.36	0	1	.85	.84
Women	.25	.43	0	1	.22	.35***
Native born U.S. citizen	.55	.50	0	1	.53	.61***
Naturalized U.S. citizen	.55	.50	0	1	.54	.60
Foreign citizen, permanent visa	.60	.49	0	1	.61	.56
Foreign citizen, temporary visa	.66	.48	0	1	.65	.71

Legend: * p<.05; ** p<.01; ***p<.001

The second indicator of the normative flexibility of friendship is its <u>adaptability to the changing context,</u> which is related to its capacity to sustain relationships over time regardless of external pressures or distance (Anderson 2001, Conradson and Lathan 2005, Hruschka 2010). In the context of science, some productive collaborative relationships are initiated during graduate studies and last throughout scientists' careers. Table 4-5 presents the results of a one-way ANOVA difference in a means test for age and the origination of the relationship for both friendship and other collaborative ties. Respondents were asked how long they had known their collaborators and where they had met the first time. The length of a relationship is coded 1 if respondents had known their collaborators for less than three years, 2 if they had known them for two to six years, and 3 if they had known them more than six years. Results show that on average respondents had known their collaborators for 3-6 years (mean 2.37) and that they had known their friends longer than other collaborators (mean 2.24 vs. 2.73). Results for the origination of relationships show that respondents were more likely to have met their friends than other collaborators in graduate school (mean .10 vs. .01) (Table 4-5). This pattern is robust across all groups of scientists and engineers (not reported). Similarly, more friends than other collaborators were on the respondents' dissertation committee, or they were their Ph.D. students.

Table 4-5 Origination of relationships: Difference in means for friendship vs. other collaborative ties

	Mean	**Std. Dev.**	**Min**	**Max**	**Mean**	**Mean**
	All N=6039				Not Friend N=4640	Friend N=1399
Age of relationship (1=less than 3 years, 2=3-6 years, 3=more than 6 years)	2.37	.74	1	3	2.24	2.73***
Alter was on ego's dissertation committee	.03	.17	0	1	.02	.05***
Alter is/was the Ph.D. student of ego	.04	.19	0	1	.03	.06***
Alter and ego were Ph.D. students together	.03	.18	0	1	.01	.10***
Legend: * p<.05; ** p<.01; ***p<.001						

Another important property of friendship for the mobilization of social capital is the strength of relationships. Two indicators of the strength of ties are the closeness of knowledge and the number of roles within the relationship (Marsden and Campbell 1984, Hruschka 2010, Harvey and Pauwels 1999, Verbrugge 1979). Knowledge closeness and multiplexity facilitates resource exchange by constraining unethical behavior and allowing for the transfer of complex or tacit knowledge (Hansen 1999, Cross and Cummings 2004, Hansen et al 2005, Hansen 1999, Krackhardt 1992, Tortoriello and Krackhardt 2010). Table 4-6 reports results from a one-way ANOVA test for the relational strength of the first two indicators. Knowledge closeness is measured by the self-assessed degree to which respondents understand the expertise of their collaborators. It is coded (1) if one has limited knowledge, (2) if one has working knowledge, and (3) if one has a detailed knowledge. Multiplexity reflects the number of roles within the relationship. The table reports both the number of roles in the relationship and the content of these roles. The survey asked respondents to name individuals to whom they turned for advice or talked about important university issues. The results show that friendships are stronger than other collaborative ties in terms of understanding both the expertise of collaborators (mean 2.97 vs. 2.81) and the roles within the relationships (mean 1.40 vs. 1.16). The results, which hold for all demographic groups of scientists and engineers (not reported), are consistent with the results of prior studies that have found that friendship tends to be more multiplex than other relationships (Hruschka 2010). With respect to the specifics of a role, the results show that scientists and engineers turn to their friends for advice more often than they do to other collaborators (mean .18 vs. .07). This finding is supported by empirical studies pertaining to advice seeking and giving behavior, suggesting that people feel more comfortable turning to their friends for advice and more willing to help their friends (McGrath et al. 2003, Saint-Charles and Mongeau 2009). Similarly, respondents discuss department or university-related issues with their friends more often than they do with other collaborators (mean .21 vs. .08), which is also supported by research on the consensus-building role of friendship in organizations (Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008). Thus, the comparison of friendships to other collaborative relationships shows that friendships are stronger than other workplace relationships. On average, friendship forms within status groups defined by perceived seniority, grant-securing ability, and gender.

Table 4-6 Strength of relationships: Difference in means for friendship vs. other collaborative ties

	Mean	Std. Dev.	Min	Max	Mean	Mean
	All N=6039				Not Friend N=4640	Friend N=1399
Strength indicators						
Knowledge closeness	2.86	.51	1	3	2.81	2.97***
Number of roles	1.21	.50	1	3	1.16	1.40***
Role specifics						
Turn to for advice	.10	.295	0	1	.07	.18***
Talk about university issues	.11	.317	0	1	.08	.21***
Legend: * p<.05; ** p<.01; ***p<.001						

Accessed social capital of those scientists who have at least one friend vs. those who do not

The networked perspective on social capital emphasizes variations in accessed social capital (Bourdieu 1986, 1991, Lin 2001, Coleman 1992). In the context of this dissertation, establishing whether and in what ways the accessed social capital of scientists who have at least one friend differs from that of scientists who do not could prove interesting. Tables 4-7 present a comparison between the selected characteristics of personal collaborative networks of scientists who have at least one friend among their collaborators to the selected characteristics of those who do not.

The results of a one-way ANOVA test show that respondents with friends had larger collaborative networks composed of stronger relationships: they had more collaborators (mean 5.68 vs. 4.38), their networks were more "U.S.-based" and "older" (5.14 vs. 3.91 and 2.46 vs. 2.28), more multiplex (mean 7.06 vs. 5.12), and characterized by higher intensity of interaction (mean 2.41 vs. 2.18). Their networks were not significantly more or less internally oriented as reflected by the EI Index. Individuals with friends retained more relationships with their dissertation advisers, their own former students, and their fellow Ph.D. classmates. They also met their collaborators at conferences more often that those who did not have friends. These results suggest that friendships in science may form around shared interests or the joint pursuits of these interests, or that scientists collaborate because they like it (Beaver 2001, Katz and Martin 1997). They also indicate that the inherent normative flexibility of friendship is conducive to bridging across the formal role hierarchy and maintaining relationships over time (Blatterer 2010, Conradson and Lathan 2005, Hruschka 2010). Consistent with the homophily literature (McPherson et al. 2001, Verbrugge 1977), those who have friends among collaborators have more gender-homophilous networks (the mean number of same gender alters 3.12 vs. 2.54). However, the collaborative networks of the two groups do not differ in terms of status, funding, or knowledge homophily: Both groups report that on average their networks are balanced in terms of status and funding homophily (mean heterophily .62 and .91). Similarly, both groups report that on average, they have close to detailed understanding, or knowledge, of their collaborators' work (mean 2.84).

Table 4-7 Accessed social capital: Respondents who have at least one friend vs. others

	Mean	**Std. Dev.**	**Min**	**Max**	**Mean**	**Mean**
	All				Has friend among closest collaborators	
	N=1191				No N=560	Yes N=631
Size and strength of ties						
# Collaborative ties	5.07	2.46	1	10	4.38	5.69***
Age of network	2.39	.50	1	3	2.28	2.46***
Frequency of interaction	2.32	.59	1	4	2.18	2.41***
# Of roles (multiplexity)	6.15	3.24	1	18	5.12	7.06***
Location and origin of ties						
EI index	.00	.02	-1	1	-.01	.02
# U.S.-based collaborators	4.56	2.36	0	10	3.91	5.14***
# Dissertation committee members	.14	.42	0	3	.10	.18**
# Ph.D. students	.19	.61	0	6	.13	.25***
# Fellow Ph.D. students	.17	.48	0	5	.06	.26**
# Number of individuals whom respondents met at conferences	.80	24	0	9	.55	1.02***
Homophily/heterophily of ties						
Gender homophily	2.85	2.38	0	10	2.54	3.12**
Status heterophily	.62	2.62	-9	9	.58	.66
Funding heterophily	.91	2.06	-6	9	.94	.89
Knowledge closeness	2.84	.43	1	3	2.81	2.86

Legend: * p<.05; ** p<.01; ***p<.001

The descriptive analysis of the properties of respondent's collaborative networks shows that respondents who have friends in their networks may be better integrated in the science community. Therefore, I examine whether the two groups exhibit consistent differences in the properties of other professional relationships (Table 4-8). The t-test results indicate that scientists who have close friends among their closest collaborators also have more research discussion ties, more career advice ties, and more departmental discussion ties. In other words, they seem to better integrate with their immediate science communities.

Table 4-8 Size of other professional networks: Respondents who have at least one friend vs. others

	Mean	Std. Dev.	Mean	Mean
	All		**Has friend among closest collaborators**	
	N=1191		No N=560	Yes N=631
Number of research discussion ties (0-5)	1.48	1.60	1.29	1.65***
Number of career advice ties (0-5)	1.56	1.55	1.27	1.82***
Number of departmental discussion ties (0-5)	2.22	1.64	1.90	2.51***

Legend: * p<.05; ** p<.01; ***p<.001

The results presented in the descriptive analysis provide supporting evidence that friendship is present among the relationships in the professional networks of academic scientists. More than half of the respondents report that they have friends in their personal collaboration networks, and almost one-third of all ties in these networks are close friendships. This finding is not surprising given the networked social structure of science, the mechanisms of the formation of scientific opinion, and the importance of relationships to the conduct of science (Bourdieu 1991, Crane 1972, Adler and Haas 1992, Merton 1973, Polanyi 2000). Even more so, it is not surprising, given that collaboration is often motivated by personal relationships (Katz and Martin 1997, Beaver 2001). With respect to the variation of the friendship patterns across different groups of scientists, it appears that U.S. scientists and engineers form their friendships primarily within the ascribed status groups defined by gender, perceived seniority, and grant-getting ability. This result is consistent with the observation that friendships tend to form between individuals of similar social status (Verbrugge 1977, McPherson et al. 2001).

The flexibility of friendship manifests primarily in its ability to maintain relationships that scientists form during their graduate studies and to bridge the status difference between scientists and students. This finding is supported by the argument that academic friendships between mentors and students are an integral part of the education of academic scientists (Anderson 2001,Waghid 2006). It is also in line with anthropological observation studies that friendships may form between individuals whose status hierarchy is defined by their role in the social structure and the interdependence of these roles, such as maids and mistresses in the study of Rezende (1999). The descriptive results also indicate that more friends than other collaborators were met at conferences, which may be an indication that academic friendships may form around shared interests.

Overall, the descriptive analysis supports the proposition that friendships exist between collaborative ties in personal collaborative networks. Friendships are formed primarily within status groups, which are defined by seniority, grant-getting ability, and gender. The status-bridging capacity of friendship primarily reflects the collaborative ties of scientists and engineers with their current or former students. The inherent flexibility in the form of the adaptability of friendship to changing contexts is primarily reflected by its capacity to maintain relationships over time. Furthermore, scientists who have friends have larger, more U.S.-based collaborative networks composed of stronger relationships.

4.1.2. Regression results

What factors explain the prevalence of friendship in the networks of the closest collaborators of U.S. scientists and engineers? While the descriptive results above are important to the understanding of some of the particularities of friendship ties in science, I also expect that some faculty members will have more friends than others. The first formal hypothesis *(H1)* states: *Senior academic scientists have more friends in their collaborative networks than junior academic scientists*.

The results from the logistic regression analysis that examines factors that explain the presence of friendship among collaborative ties shows that the strongest and the only positive and statistically significant predictors of whether academic scientists have friends in their collaborative networks are that scientists have academic spouses and that they are native-born scientists. As shown in Table 4-9, having a faculty spouse increases the probability of having a close friendship among collaborative ties by 64%. This finding is noteworthy and supported by prior research that has highlighted the importance of the academic lifestyle and mutual embeddedness of the lives of academic spouses in the formation of their social relationships (Austin 2002, Etzkowitz et .992, Fox 2005, Rusconi and Solga 2008). Being a foreign citizen also decreases the probability of having a close friendship by 65%. These results underscore the importance of the social aspects of friendship development.

Contrary to the expected results, results show that having a close friend among the closest collaborators is not explained by seniority or accomplishments within the science community. Coefficients on the years since one earned a Ph.D., the number of offices currently held by a respondent, and the number of grant proposals on which a respondent was the PI or co-PI are not significant. The results from the Wald test for this group of variables are also not significant (chi2(3)=5.06, Prob > chi2 =.1672). Instead, it appears that having at least one close friend among the closest collaborators is primarily explained by demographic factors. With respect to the effects of context, the results are inconclusive. While none of the coefficients for the context variables are significant, the

Wald test results for the group of context variables are significant (chi2(5)=11.64, Prob > chi2=.04).

The results from the negative binomial regression analysis (which estimated the effects of seniority on the prevalence of friendship among collaborative ties) only partially support this hypothesis. The results show that seniority, measured as the number of years since one earned a Ph.D. has no impact on having close friends among collaborative ties. However, scientist's accomplishments do. Each office in a professional association that a respondent currently holds increases the expected mean number of friends by 19%. Each grant proposal submitted over the past two years (on which the respondent was the PI or co-PI) increases the expected mean number of friends by .7%. Respondents who are in leadership positions and who are more active in the science community have more friends in the networks of their closest collaborators than less central and active scientists.

With respect to demographic variables, the results show that having a faculty spouse increases the expected mean number of friends by 10%. The finding that overall seniority has no effect on the prevalence of friendship in collaborative networks is contrary to the expected finding. The result that friendship is not affected by the size of a respondent's department is supported by the argument that networks are personal, including those in science (Crane 1972, Wellman 2007).

Being a naturalized citizen decreases the expected mean number of friends by 8%, and being a foreign citizen by 14%. Finally, results show that the discipline of science does not impact whether respondents have friends in their networks or not (Model 1.1), but it does impact the number of friends (Model 1.2). The results show that the discipline of computer science is somewhat similar to the discipline of biology (reference group) in terms of the prevalence of friendship. Respondents from the discipline of earth and atmospheric sciences, however, have more friends among their collaborators; and respondents from the disciplines of chemistry and electrical engineering have fewer friends.

Table 4-9 Prevalence of friendship: Logistic and negative binomial models[5]

N=906	Has at least one friend (Model 1.1[6])		Number of friends (Model 1.2[7])	
	Coef.	**% change**	**Coef.**	**% change**
Independent Variables:				
Seniority and accomplishments in the science community				
Career age	.00	-1.0	.00	.0
Number of offices in professional associations	.23	25.7	.17*	18.6
Number of grant proposals	.01	1.3	.01*	7.0
Other Independent Variables:				
Demographic Characteristics and Context				
Female	.11	12.0	-.05	-2.6
U.S. naturalized citizen	-.36	-30.2	-.25*	-8.3
Foreign citizen	-.61**	-45.9	-.37***	-13.6
Academic family background	-.17	-16	-.08	-3.1
Academic spouse	.64***	89.1	.21*	10.0
Department size	.00	.3	.00	2.3
Chemistry	-.34	-28.8	-.32**	-30.6
Computer science	-.03	-2.7	.05	.5
Earth and atmospheric sciences	.26	29.4	.28**	32.4
Electrical engineering	-.33	-27.8	-.32*	-27.2
Legend: * p<.05; ** p<.01; ***p<.001	LR chi2(13)=52.50 Prob>chi2=0		LR chi2(13)=82.17 Prob>chi2=0	

[5] Summary statistics for the estimations sample for Model 1 are provided in Appendix Table A-1.
[6] Logistic regression
[7] Negative binomial regression

Thus, how prevalent is friendship in academic science? The results of the explanatory analysis show that while friendship is present in the collaborative networks of more than half of academic scientists and engineers, it is not equally available to all of them. Scientists who are born in the U.S. and who have academic spouses are more likely to have friends among their closest collaborators. That is, friendship is more available to scientists who are more embedded both personally and professionally. Thus, I find that the prevalence of friendship is determined by scientists' demographic characteristics, personal factors, such as their type family, their standing in the professional community, and their productivity-related accomplishments. This finding is in line with work that alludes to the existence of a core social group in U.S. science, or an inner circle, that is well integrated within the interpersonal networks of science on both personal and professional levels and for which science is a "way of life" (Austin 2002, Crane 1972, Etzkowitz et al. 1992, Fox 1991, 2005, Zuckerman et al. 1991, Wagner and Leydesdorf 2005). Moreover, this finding highlights how intertwined the professional relationships of academic scientists are with their social and personal relationships (Fox 2005, Rusconi and Solga 2008).

4.2. Effects of Friendship on the Mobilization of Network Resources

To answer the second research question of this dissertation "How does friendship affect the exchange of resources relevant to productivity in the professional networks of academic scientists?" this section will first examine whether friendships provide more and/or different types of resources relevant to publication productivity than other collaborative ties. It will then examine whether scientists who have personal networks comprised of more friendships are able to mobilize more resources from their networks than scientists who have networks comprised of fewer or no friendships.

4.2.1. Descriptive results

Do friendships provide more and/or different types of productivity-relevant resources? To answer this question, I compare friendships with other collaborative ties. As shown in Figure 4-1, a larger percentage of friendships are a source of collaboration on grant proposals, academic journal articles, and book reviews than other collaborative ties (52% and 57% vs. 43% and 36%, respectively). Similarly, a larger percentage of friendship ties provide reviews of papers and proposals, introductions to potential collaborators, and endorsements of reputation in the form of nominations for awards or as invited speakers (44%, 47% and 25% vs. 17%, 24%, 10%). It is interesting to note that the concurrence of paper or proposal reviews is more than three times as high for friends as it is for other collaborators (44% vs. 17%). The results from the one-way ANOVA difference in the means test indicate that all of the differences are significant (Table 4-10). Friendship ties also provide a significantly greater range of resources than other non-friend collaborative ties (mean range 2.24 vs. 1.30). This finding is consistent with that of work suggesting that stronger relationships allow the transfer of more resources (Hansen 1999, Cross and Cummings 2004, Hansen et al. 2005, Podolny 2001).

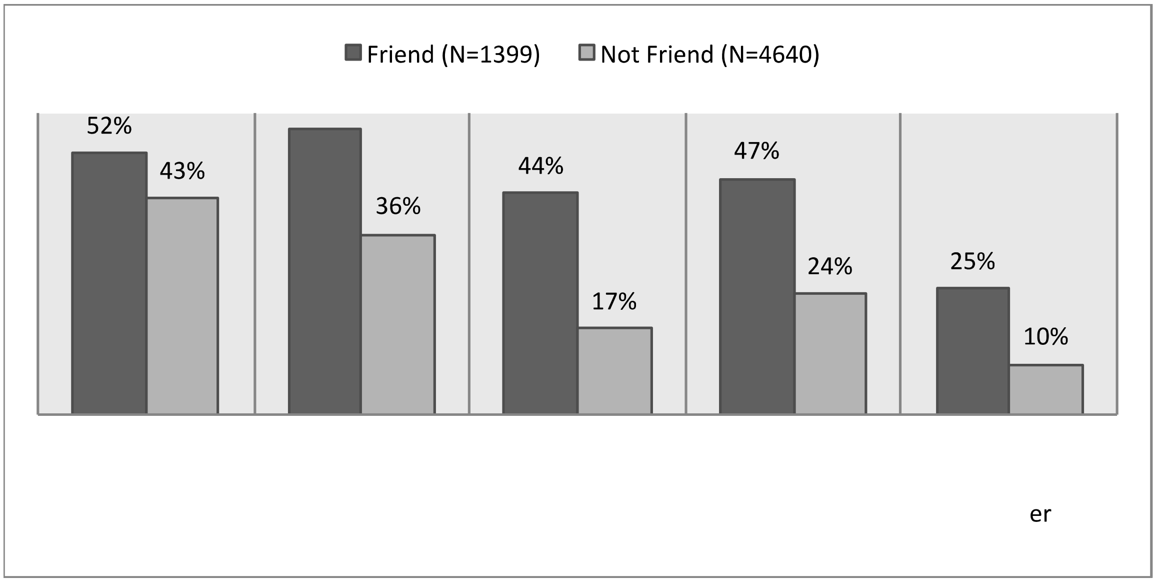

Figure 4-1 Productivity-relevant resources mobilized from friends and other collaborators.

Table 4-10 Mobilized resources: Difference in means for friendship vs. other collaborative ties

N=6039	Mean	Std. Dev.	Min	Max	Not Friend (N=4640)	Friend (N=1399)
Collaboration on research grant proposals	.45	.498	0	1	.43	.52***
Collaboration on academic journal articles/book chapters	.41	.492	0	1	.36	.57***
Paper or proposal reviews	.23	.423	0	1	.17	.44***
Introductions to potential collaborators	.29	.454	0	1	.24	.47***
Nominations for award or as invited speaker	.14	.342	0	1	.1	.25***
Range of resources	1.52	1.25	0	5	1.30	2.26***

Legend: * p<.05; ** p<.01; ***p<.001

The results of the descriptive analysis show that a higher share of friendship ties provide each of the analyzed types of resources and a greater range of resources than other collaborative ties. This finding is consistent with the findings from knowledge transfer studies that strong ties allow the transfer of more resources between individuals than weak ties (Hansen 1999, Cross and Cummings 2004, Hansen et al. 2005, Podolny 2001).

4.2.2. Regression results

Does friendship increase resource mobilization from collaborative networks? The second formal hypothesis (H2) states: "Scientists with more friends in their networks mobilize more resources through their networks than scientists with fewer friends." The results of the analysis provide strong support for this hypothesis. The results from the explanatory model show that friendship has a positive effect on both the total number of resources mobilized from networks and collaboration on journal papers and book chapters. Table 4-11 reports results for the model in which the total number of mobilized resources (Model 2.1.) and collaboration on journal papers or book chapters (Model 2.2.) is explained by the number of friends in the network of one's closest collaborators.

The results show that larger networks comprised of more friends provide more resources. This finding is supported by the networked social capital argument that resources are embedded in networks and the nature of relationships is important in the process of the mobilization of these resources (Lin 1999, 2001, Podolny and Baron 1997). Each additional collaborative tie increases the mean expected total of mobilized resources by 20%, and if the tie is friendship, it increases it by an additional 5%. Similarly, each additional collaborative tie increases the mean expected number of mobilized collaborations on journal papers and book chapters by 20%, and if this tie is friendship, it increases it by an additional 4%. None of the demographic variables affect the total number of mobilized resources (the result of the Wald test for this group of variables is also not significant, chi2(4)=3.77, Prob>chi2=.44). Therefore, it is plausible that the ability of scientists and engineers to mobilize resources is primarily explained by the relational properties of the collaborative network. Consistent with the Matthew Effect observed in the bibliometric and social studies of science, senior scientists are more likely to mobilize collaboration from their networks than junior scientists (Fox 1983, Stephan 1996, 2007 among others).

Table 4-11 Effect of friendship on resource mobilization: Negative binomial model[8]

N=906	Mobilized total of resources (Model 2.1.)		Mobilized collaboration on journal papers or book chapters (Model 2.2.)	
	Coef.	**% change**	**Coef.**	**% change**
Independent Variable				
Number of friends	.05***	5.2	.03*	3.5
Other Independent Variables: Network properties				
Size of network	.18***	19.5	.18***	19.9
Demographic Characteristics and Context				
Female	.00	.2	.01	.6
U.S. naturalized citizen	.01	-.3	.02	.7
Foreign citizen	-.06	.6	-.02	-.8
Career age	.00	-6.0	.01**	8.7
Chemistry	.00	.5	.13	5.4
Computer science	-.04	-3.6	-.04	-1.6
Earth and atmospheric sciences	.01	1.0	.05	2.0
Electrical engineering	-.11*	-10.4	-.26**	-9.0
Legend: * p<.05; ** p<.01; ***p<.001	LR chi2(10)= 655.97 Prob>chi2=0		LR chi2(10)=298.66 Prob>chi2=0	

4.3. Effects of Friendship on Publication Productivity

To answer the third research question "How does friendship affect scientist's publication productivity?" this section will report the results of the analysis that addresses whether scientists who have personal networks comprised of more friendships have more publications in WoS-indexed journals. To address this question, I examine the effects of friendship-based resources and resources mobilized through other sources by first linking

[8] Summary statistics for the estimations sample for Model 2 are provided in the Appendix Table A-2.

friendship to the raw count of publications, a measure of collaborative productivity (Tables 4-12 through 4-15) and then linking friendship to the fractional count of productivity, a measure of personal productivity (Table 4-15). Summary statistics for the estimations sample for Model 3 are provided in Appendix Table A-3.

The third formal hypothesis (H3) states: "Scientists with more friends in their professional networks are more productive than scientists with fewer friends." The results (shown in Tables 4-12 through 4-14) demonstrate that friendships with collaborators facilitate both *collaborative and personal publication productivity.* Each friend in respondent's collaborative network increases the expected mean count of publications by 22 to 23% (Table 4-12). This finding is supported by the literature, which suggests that networks of relationships comprised of both social and personal dimensions are more conducive to the mobilization of social capital (Uzzi 1998, Lin 2001). It is also in line with the literature that suggests that people nurture their productive relationships (Conradson and Lathan 2005, Hruschka 2010). It is interesting to note that the size of a collaborative network has no effect on publication productivity. This result is in line with prior research that has found that the number of collaborative ties per se may not have direct effects on publication productivity (Lee and Bozeman 2005).

To extend this analysis, the social capital literature suggests that different ties may be a source of different types and quality of resources (Coleman 1992, Podolny and Baron 1997). Therefore, to examine whether resources mobilized from friends affect productivity differently from resources mobilized from other collaborators, I have depicted mobilized resources as two separate variables. Models 3.1c and 3.1d include this expanded version of mobilized resources, which includes resources mobilized from friends and resources mobilized from other collaborators (Table 4-13). The results show that both the total number of resources or the collaboration on papers and books mobilized from friends, and the resources mobilized from other collaborators have a positive effect on productivity. However, resources mobilized from friends have slightly less effect on productivity than resources mobilized from other collaborators.

As could be expected, the external orientation of the network, reflected by the EI-Index, has a positive effect on collaborative publication productivity (Burt 1992, Nahapiet and Goshal 1998, Oh et al. 2006). With respect to the variation in productivity across demographic groups, the results suggest that women are as productive as men in the terms of publication count, but less productive in terms of personal productivity. These results are in line with research that found evidence of variations in publication productivity by gender and the cumulative nature of advantage and disadvantage in publication productivity (Cole and Cole 1973, Fox 1983, Larivivière et al. 2011, Levin and Stephan 1991, Long 2001, Smith-Doerr 2004, Whittington and Smith-Doerr 2005). Consistent with prior research, foreign citizens are more productive that U.S. native-born citizens. Being a foreign citizen increases the expected mean number of publications by 39%. However, the effect of tenure in the profession is nil or negative. Each additional year since one earned a Ph.D. decreases expected mean productivity by .6-.8% (Model 3.1b in Table 4-12 and Model 3.1d in Table 4-13). This finding is consistent with that in the literature: that publication productivity decreases with career age (Levin and Stephan 1991, Carayol and Matt 2006 among others).

Table 4-12 Effects of friendship for total publication productivity: Negative binomial (Models 3.1a and 3.1b)

N=906	Total Publication Count 2007-2009			
	Model 3.1a		Model 3.1b	
	Coef.	% change	Coef.	% change
Independent Variable				
Predicted number of friends	.2**	22.2	.21**	23.2
Other Independent Variables: Network properties				
Network size	.01	1.4	.01	1
EI-index	.16***	17.2	.13**	13.4
Total mobilized resources	.02***	2.5		
Mobilized collaboration journal papers and book chapters			.1***	1.2
Resources				
Grant resources (#of graduate students)	.07***	7.6	.07***	7.6
Demographic Characteristics and Context				
Female	-.09	8.9	-.08	-7.7
U.S. citizen (naturalized)	.09	1.0	.09	9.7
Foreign citizen	.39***	47.6	.38***	45.9
Career age	-.0	-.3	-.01**	-.6
Chemistry	.26***	29.5	.25**	28.2
Computer science	-.61***	-45.5	-.59***	-44.7
Earth and atmospheric sciences	.04	-4.1	.04	-3.6
Electrical engineering	.01	-1.3	.05	5.1
Legend: * p<.05; ** p<.01; *** p<.001	LR chi2(14)= 346.6 Prob > chi2=0		LR chi2(14)=382.88 Prob > chi2=0	

Table 4-13 Effects of mobilized resources for total publication productivity: Negative binomial model (Models 3.1c and 3.1d)

N=906	Publication Count 2007-2009			
	Model 3.1c		**Model 3.1d**	
	Coef.	**% change**	**Coef.**	**% change**
Independent Variable				
Predicted number of friends	.2**	21.7	.18*	18.3
Other Independent Variables: Network properties				
Network size	.01	1.3	.02	2.1
EI-index	.16***	17.2	.15*	16.3
Total mobilized resources from friends	.03***	2		
Total mobilized resources from others	.13***	2.8		
Mobilized collaboration on journal papers and book chapters from friends			.06*	6
Mobilized collaboration on journal papers and book chapters from others			.07***	7.3
Resources				
Grant resources (#of graduate students)	.13***	13.9	.1***	1.7
Demographic Characteristics and Context				
Female	-.09	-8.9	-.12	-1.9
U.S. citizen (naturalized)	.09	9	.07	7.3
Foreign citizen	.38***	46.2	.31***	36
Career age	.0	.3	-.01*	-.8
Chemistry	.25***	28.1	.24*	26.7
Computer science	-.61***	-45.7	-.53*	-41.1
Earth and atmospheric sciences	.04	4	-.53	-4.1
Electrical engineering	.02	2.3	.04	-9.8
Legend: * p<.05; ** p<.01; *** p<.001	LR chi2(14)=346.82 Prob > chi2=0		LR chi2(15)= 18.32 Prob > chi2=0	

Table 4-14 Effects of friendship for fractional publication productivity: OLS regression model (Model 3.2)

N=906	Fractional Publication Count 2007-2009	
	Coef.	**Beta**
Independent Variable		
Predicted number of friends	.37*	.1
Other Independent Variables: Network		
Network size	.01	.01
EI-index	.36***	.09
Total mobilized resources	.03*	.08
Resources		
Grant resources (#of graduate students)	.32***	.4
Demographic Characteristics and Context		
Female	-.37***	-.09
U.S. citizen (naturalized)	.24	.04
Foreign citizen	.80***	.15
Career age	-.01	-.03
Chemistry	.49**	.1
Computer science	-.97***	-.18
Earth and atmospheric sciences	-.11	-.02
Electrical engineering	.09	.02
Legend: * p<.05; ** p<.01; *** p<.001	Adj. R-squared=.23	

4.4. Summary of Findings

This dissertation argues that friendship is a natural and omnipresent social relationship that facilitates the mobilization of social capital for individual goal attainment; therefore, it not only represents an inherent part of the personal professional networks of academic scientists and engineers but also impacts the attainment of the institutional goal of science: the production of scientific knowledge. Based on the analysis presented in this chapter, Table 4-15 presents a summary of the results and findings.

Based on the broad review of the conceptualization of friendship in the relational, philosophical, sociological, anthropological and organizational literature, I argued that friendship is present in the personal professional networks of academic scientists, a proposition strongly supported by the results of this study. More than half of the respondents have at least one friendship among their closest collaborative ties. However, the friendships of U.S. scientists and engineers form primarily within ascribed status groups defined by their perceived seniority, grant-getting ability, and gender. The inherent flexibility of friendship, which, according to the reviewed literature, contributes to the integration of social structures, manifests in friendships between individuals whose status differences are defined by their institutional roles and in friendships between individuals who were Ph.D. classmates.

The second argument presented in this dissertation, supported by the reviewed literature, is that the prevalence of friendships in the personal professional networks of academic scientists might be explained by their seniority and accomplishments in the science community. Therefore, I hypothesized that more senior and central scientists and engineers will have more friends. The rationale for this hypothesis is that more senior scientists and engineers may have had more time to find similar colleagues and that older individuals tend to be more selective in their social contacts and perceive them more positively. More senior, central individuals also have higher job autonomy and are given preference by those who are less senior or central. The results only partially support this hypothesis. The accomplishments within the science community (conceived as the number of current offices and grant-getting activity) have a positive impact on the number of friendships among collaborative ties. Seniority (conceived as the time since one earned a Ph.D.), however, has no effect on having friendships among collaborative ties. It appears that whether respondents have at least one close friend among their closest collaborators is primarily explained by demographic and personal factors. Having a faculty spouse doubles the likelihood of having a close friend among one's closest collaborators. The finding that the type of family affects the prevalence of friendship within personal collaborative networks highlights how interlaced professional and personal relationships in science are (Fox 2005, Rusconi and Solga 2008)

Being a foreign citizen decreases the likelihood of having a close friend by 65%. Taken together with the finding of the descriptive analysis of the properties of the properties of collaborative networks of respondents, which show that scientists with friends have larger, more U.S.-based networks comprised of stronger relationships, the finding that foreign citizens are less likely to have friends may suggest that friendships form between scientists and engineers who are better integrated in the U.S. academic community. This finding is supported by the general argument from the anthropological literature that patterns of friendship vary according to the major social division of a given society (Adams et al. 2000, Allan 1998, Doyle and Smith 2002, Grey and Sturdy 2007, Lazarsfeld and Merton 1954, Mao 2006, O'Connor 1998, Verbrugge 1977).

The third argument of this dissertation is based on the reviewed social capital, organizational, and knowledge transfer literature, I argued that friendship facilitates resource mobilization because it facilitates advice seeking and giving as well as the transfer of knowledge, especially complex and tacit knowledge. I hypothesized that scientists with more friends in their networks will mobilize more resources from these networks. The results of this study provide strong supporting evidence for this hypothesis. The descriptive results show that friendships provide more of all of the analyzed types of resources than other collaborative ties. The results from the analytical model show that friendship has a positive effect on both the total number of mobilized resources and the mobilized collaboration on journal papers and book chapters (a resource directly related to publication productivity). The results also suggest that it is senior scientists and engineers who mobilize more collaboration on journal papers and book chapters from their networks.

Finally, based on the literature, which links social capital to knowledge creation, I explained two main mechanisms by which friendship facilitates publication productivity. The first mechanism is the above described resource mobilization. The second is the integration of social capital, which, in turn, facilitates the effective use of these mobilized resources. I hypothesized that scientists with more friends in their professional networks are more productive than scientists with fewer friends. The results of the core explanatory model show that friendships have a positive effect on a scientist's publication productivity: each friend, by increasing the expected mean number of publications by 22%, has a positive effect on personal productivity. The relative strength of the effect of friendship is similar to the effect of the external orientation of the collaborative network.

Table 4-15 Summary of findings: Hypothesized relationships and evidence

Argument	Hypothesis	Support	Evidence
Friendship is a natural and omnipresent personal relationship that integrates networked social structures.	*P1 Friendship is present among the relationships in the professional networks of academic scientists*	Yes	• 54% of respondents have at least one friendship among collaborative ties
Prevalence of friendship varies across demographic groups.	*H1 Senior academic scientists have more friends in their collaborative networks than junior academic scientists*	Partial	***At least one friendship among collaborative ties*** • Seniority variables do not affect the probability of having a friendship among collaborative ties • For foreign citizens, the probability of having friends among collaborative ties is 65% lower than it is for native-born U.S. citizens • For respondents with an academic spouse, the probability of having friends among collaborative ties is 65% higher than for other scientists ***A number of friendships in collaborative networks*** • Time since earning a Ph.D. has no effect on the number of friendships among collaborative ties • Each currently held office in the professional association increases the expected mean number of friends among collaborative ties by 19% • Each grant proposal on which a respondent is the PI or co-PI increases the expected mean number of friends among collaborative ties by 7%
Friendship facilitates mobilization of publication productivity relevant resources.	*H2 Scientists with more friends in their networks mobilize more resources through their networks than scientists with fewer friends*	Yes	• Each friendship increases the expected mean of the total number of mobilized resources by 5% and the expected mean number of collaboration on journal papers and book chapters by 4%
Friendship facilitates mobilization of social capital for individual goal attainment.	*H3 Scientists with more friends in their professional networks are more productive than scientists with fewer friends*	Yes	• Each friendship increases the expected mean number of publications by 22%

5. CONCLUSIONS AND POLICY IMPLICATIONS

In this dissertation, I reasoned that processes of academic productivity are inherently social (Bourdieu 1991, Bozeman et al 2001, Fox and Mohapatra 2007, Latour 1982, Merton 1973, Nahapiet and Goshal 1998, Nonaka and Takeuchi 1991). In these processes, instrumental relations are “embedded” in social and personal relations (Granovetter 1985, Uzzi 1998), and competition is not perfect (Ginther 2006). Therefore, I posited that friendship, being a very special social relationship, plays a predictable role in these processes.

Analyzing the personal collaborative networks of U.S. scientists and engineers, I found that friendship is important for productivity in science. Further, my results suggest that that a successful productivity strategy may be to utilize strong tie-based relational social capital, which complements structural social capital for the purposes of publication productivity. My findings pertaining to friendship in the academic environment are consistent with observations of its patterns in other settings. Specifically, I found that friendships are present in informal workplace networks (Dickie 2009, Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008, Mao 2006, 2009, Morrison 2004, Song and Olshfski 2008, Tse et al. 2008), they form within ascribed status groups (Lazarsfeld and Merton 1954, McPherson et al. 2001), they support relationships over time (Conradson and Lathan 2005, Hruschka 2010), they are characterized by higher resource exchange (Hansen 1999, 2002, Levin and Cross 2004, Phleps et al. 2012, Podolny 2001, Reagans and McEvily 2003, Tortoriello and Krackhardt 2010), and most importantly, they have an impact on organizational outcomes (Berman et al. 2002, Crabtree and Space 2004, Farrell 2001, Nielsen et al. 2000).

With respect to the role of friendship in science, I found that friendship in science is particularly important to academic productivity and that it integrates the scientific community. In short, I found that scientists who collaborate with their friends are more productive. Therefore, friendship is a potent resource for the attainment of the institutional goals of science. The observed prevalence of friendship in the personal collaboration networks of U.S. academic scientists and engineers, the evidence about its formation within the perceived status groups and variation across the demographic groups, its direct positive effects on the mobilization of resources, and publication productivity have several theoretical and policy implications. In this chapter, I will discuss the core findings of the dissertation and present its theoretical and practical contributions and policy implications.

5.1. Core Findings: The Prevalence and Effects of Friendship in Science

The core finding of this dissertation is that friendship is important for (a) productivity, and thus the attainment of the institutional goal of science, and (b) the integration of the informal structures of science. It not only represents a part of the relationships that constitute personal collaboration networks of U.S. academic scientists and engineers, but also has a direct positive effect on both the mobilization of resources from these networks and publication productivity. In other words, scientists who collaborate with their friends are more productive. In addition, while friendship is fairly prevalent—with more than a half of respondents having at least one friend among their closest collaborators—U.S. native-born citizens and scientists with a faculty spouse are more likely to have friends than foreign citizens and scientists with spouses or partners outside of academic science. Moreover, scientists who are more active in grant acquisition and who hold more offices in professional associations have more friends among their collaborators. This finding indicates the importance of joint activities for the integration of the science community. It also suggests that professional relationships in science are closely intertwined with social and personal relationships and that the networks of these relationships, in fact, overlap to a great extent. The fact that having an academic spouse or parents is strongly associated with the number of close friends among scientists' closest collaborators deserves future exploration as a form of joint social capital of academic couples.

With respect to the effects of productivity, I find that collaboration with friends is not only positively associated with productivity, but also that its effects are comparable to those of collaboration across institutional boundaries. It suggests that the relational aspects of collaboration are an important productivity factor that should not be neglected. Prior empirical research has documented that high research productivity is strongly associated with a number of individual, institutional, and leadership factors (Bland et al. 2002, 2005). According to Bland and colleagues (2002, 2005), of the effects of these three sets of factors, individual factors are essential, but their effects can be either increased or moderated by the research-conduciveness of the institution; and the institutional effects are mediated by the properties of its leadership. Interestingly, the factor analysis in the second study of these authors suggests that personal professional ties within one's institution can be attributed to institutional factors while professional ties outside of one's institution can be associated with personal factors (Bland et al 2005). Thus, their results may be interpreted so as to conclude that external professional ties are both personal and instrumental while internal professional ties are primarily instrumental.

Important in the context of the focus on friendship is that their finding emphasizes the importance of personal relations in scientific research. My finding that the external orientation of networks has positive effects on both collaborative and personal productivity (conceived as the total publication count and fractional publication count) is in line with their findings. Furthermore, the finding that friendship has a direct positive effect on productivity, which extends beyond the effects of the external orientation of networks and the resources mobilized from them suggests that friendship is important for the attainment of the institutionalized goals of science. While in modernity, unlike in antiquity, friendship may not be important for "survival" (Hruschka 2010), it facilitates the productivity of individuals. In addition, the network theory of social capital distinguishes between accessed and mobilized social capital (Lin 2001). The finding that friendship has a strong positive effect on the mobilization of network resources suggests that the personal aspects of relationships are important is in agreement with the finding of empirical research, which has demonstrated that strong ties facilitate knowledge transfer. (Empirical evidence, primarily from the private sector, documents how personal relationships affect productivity (Hansen 1999, Cross and Cummings 2004, McFadyen 2009, Rost 2011, Tortoriello and Krackhardt 2010).) Friends, more than other ties, provide all types of analyzed resources, including collaboration on grant proposals, journal papers, and book chapters, advice on obtaining grants, introduction to new collaborators outside of the university, and endorsements of reputation. Thus, the effects of friendship extend beyond merely rendering science as more enjoyable within a workplace.

This research also found that friendship is fairly prevalent—more than half of respondents have at least one friend among their closest collaborators. Nevertheless, it is not equally available to all. As mentioned above, the findings of this dissertation indicated that U.S. native-born citizens are more likely to have friends than foreign citizens, and scientists who have a faculty spouse are more likely to have friends than those who have a spouse or a partner outside of academic science. I also found that scientists who are more active in grant getting and who hold more offices in professional associations have more friends. This finding points to the role of friendship in the integration of social capital. Along with the descriptive results—that friendships form within the perceived status groups defined by seniority, grant-getting ability, and gender—this finding illustrates the social division in U.S. academic science along the lines of merit and gender, both of which are hierarchical (Fox 2006).

5.2. Theoretical Contributions

Theoretical implications pertain to theorizing about the role of friendship within the networked social structure of science, the conceptualization of the role of structure of relationships in the mobilization of social network resources for individual goal attainment, and theorizing of publication productivity on an individual level. This dissertation drew from a broad range of social science literature, the goal of which was to collect information that examined both friendship and individual productivity from a broader organizational or institutional perspective. Therefore, its findings contribute to theoretical scholarly discussion, including that related to social networks and organizational theory, social network methods, and the framework of S&T human capital.

5.2.1. The role of friendship in the networked social structure of science

The results suggest that friendship is a part of the considerable share of professional ties of U.S. academic scientists and engineers and that its prevalence systematically varies across groups of scientists. The observed prevalence of friendship among the collaborative ties of scientists and engineers provides evidence that in the context of U.S. academic science, professional relationships have both social and personal dimensions. Thus, we see that individuals naturally develop personal professional communities in which professional and social relationships are deeply intertwined (Kadushin 2012, Krackhardt 1992, Krackhardt and Kilduff 1990, Kilduff and Krackhardt 2008). Such relationships, however, form primarily within perceived status groups defined by age and the ability to secure grants and achieve seniority; they do not form across these groups. The only status groups bridged by friendship are those defined by the formal roles of a student and a supervisor, suggesting that professional friendships may play a role of integrating personal communities within status groups instead of bridging these status groups; thus they integrate a broader science community. This finding is supported by Gibbons and Olk (2003), who observed that the structural similarity of individuals precedes friendship and suggested that this observation illustrates how an individual's need for cognitive balance affects the development of system-wide friendship. It may also suggest that the perceived status groups form a primary social division in the U.S. science community (Adams and Allan 1998). If true, this finding mimics social stratification on the research team level, observed by Jones et al. (2008) in their multi-university research team study in which the authors examined 4.2 million papers published over three decades and found that multi-university collaborations were increasingly stratified by in-group university rank. The authors reasoned that the intensification of social stratification in multi-university collaborations might be an illustration of the concentration of the production of scientific knowledge in fewer rather than more centers of high-impact science.

The evidence also suggests that collaborative relationships, which consist of both professional and personal dimensions, are not equally available to all scientists and engineers. Because professional friendships are more available to scientists whose spouses or partners are fellow faculty member, this finding suggests the existence of a group of scientists for whom their professional lives intersect with their family and social lives. Furthermore, professional friendships are less available to foreigners. Because scientists who hold more offices in the professional associations and submit more grant applications have more friends, the ability to secure grants is arguably an important professional capability and a form of professional merit (Freeman 2011). These observations point at the processes of preferential attachment: that more “native,” more central, and more active scientists with larger personal networks have more friends. Such self-organization, which manifests itself in the formation of not only personal communities of scientists but also epistemic communities, scientific opinion, and “invisible colleges,” is a vital aspect of the networked social structure of science (Crane 1972, Adler and Haas 1992, Polanyi 2000, Davenport and Hall 2002, Leydesdorff and Wagner 2008). The literature that has addressed the role of friendship in social structures has described friendship as a form of “social glue” or a solidarity-based relationship that integrates these social structures (Pahl 2000, Spencer and Pahl 2006, Krackhardt and Kilduff 1990). The results observed here provide evidence supporting the existence of a relatively well-integrated “core” of scientists and engineers, the networks to which entry is possible via three mechanisms: by forming friendships with fellow students during graduate studies, by forming friendships with advisors or their own students, and by forming interest-based friendships with fellow scientists. The results also point to the effects of fundamental social forces such as the distinction between the “in-group” and “others” and the possible gatekeeping role of friendship in the social structure of science.

5.2.2. The role of the structure of relationships in the mobilization of social network resources for individual goal attainment

The evidence of the direct positive effects of friendship on the mobilization of resources from collaborative networks emphasizes the importance of the role-composition of ties that comprise these networks. Thus, scientists and engineers are able to mobilize more resources as well as the authorship from networks in which professional roles are layered with social and personal roles. Overall, this finding is supported by the advice and knowledge transfer literature, which has emphasized the role of friendship, especially in situations of high uncertainty or ambiguity (Cross et al. 2001, Hansen 1999, Granovetter 1985, McGrath et al. 2003, Uzzi 1998). More importantly, the results indicate that it is the quality of relationships, not personal or contextual factors, that affects the mobilization of resources. Taken together with the above-discussed observation that friendships primarily are formed within perceived status groups defined by grant-securing ability, seniority, and gender, this finding may indicate that in the context of U.S. academic science, friendship supports the perpetuation of these status groups.

5.2.3. Publication productivity and quality of relationships

The core finding of this dissertation is that collaboration with friends has a positive effect on scientist's publication productivity. This finding contributes to the small but growing recent body of literature that links the properties of personal networks of scientists and engineers to knowledge creation and productivity. The findings of this work agree with and complement the findings of McFadyen et al. (2009), Rost (2011), Sosa (2011) and Tortoriello and Krackhardt (2010). These studies have highlighted the important roles of both the structure of networks and the quality of relationships and suggest that sparse networks of strong relationships may benefit scientific productivity.

By modeling the mechanisms by which friendship affects publication productivity, I expanded the conventional knowledge production function to include scientists' social capabilities. The social capabilities of a scientist refer to his or her capability to obtain knowledge creation opportunities, engage in collaborative activity, which implies but is not limited to pooling resources from various sources, and to establish the quality of the created knowledge and disseminate it. These additions to the conventional perception of scientific productivity enable us to account for the processes that precede and follow actual knowledge creation through exchange and combination.

5.2.4. Social network and organization theory

One of the aims of this dissertation was to contribute to the social network literature by addressing the problem of multiplex relationships (Monge and Contractor 2003, Wasserman and Faust 1994). In their book *Theories of Communication Networks*, Monge and Contractor called for stepping away from the conventional way of treating personal relationships as consisting of a single type of relationship between individuals.

That is, I utilized the overlap between the name and function-based relationship generators typically used in social network analysis and demonstrated that the overlap can be used in a meaningful way to describe the multiplex nature of personal relationships.

Overall, my findings illustrative the social dynamics described by Charles Kadushin in his recent book *Understanding Social Networks: Theories, Concepts, and Findings* (Kadushin 2012). In his book, the author suggests that dispersed social networks define social organizations of our time. In other words, as the organizing units of a society, groups have transformed from place-based relations and networks into communities structured as geographically dispersed social networks. An important feature of these geographically dispersed communities is that they emerge around individuals. In fact, it is individuals who create their "own mix of communities," and in some cases, focal individuals may be the only contacts of their communities (Kadushin 2012, p. 62). The analysis of the personal (egocentric) networks of academics perfectly suits our understanding of the dynamics of the so-conceived social structure for several reasons, primarily because of the relatively high individual autonomy. If we view an organization in terms of social networks, questions of the effectiveness and the efficiency of these networks becomes a central concern; consequently, an understanding of the "fundamental duality" of cohesion and brokerage becomes a key problem of social network theory (Kadushin 2012). A source of this duality, or paradox, stems from ambivalence toward the requirements of success in a modern society. Kadushin posits that communities emerge through the agency of talented individuals making connections to unconnected nodes. Therefore, modern societies require talent conventionally associated with brokerage and so-called "structural holes." At the same time, these "structurally autonomous" brokers who manipulate such structural holes or disconnect between people at least partially depend on their own "base" for support, a situation conventionally associated with cohesion. The author suggests that relationships within the "base" and across its borders can be best understood as relationships with both group insiders and outsiders. Relationships with insiders are more dense, supportive, and trusting. Relationships with outsiders are less dense and therefore open to manipulation afforded by structural holes. In essence, the dichotomy of insider and outsider relations, manipulation and trust behaviors, arms-length and embedded relationships as well as hit-and-run and care strategies reflect the normative dichotomy of universalism and particularism. This dichotomy is an aspect of the normative ambivalence of science, that is, the observation that for any established norm, an established counter-norm exists (Mitroff 1974, 1976). In fact, normative ambivalence is a necessary condition for the rationality of science (Merton 1973[1957], Mitroff 1976). According to Mitroff (1976), well-structured problems (typical for normal-science) are usually independent from the personalities of the individuals who formulated them and seem to be impersonal; thus, they are governed by the conventional norms of science, such as universalism. Ill-structured problems, by contrast, are intensely personal and the product of their creators, and they are governed by a norm of particularism. Thus, scientists who persevere in solving problems may, in fact, have to rely more on collaborative ties, which are comprised of not only professional but also personal roles.

The findings of my dissertation contribute to the discussion about the micro foundations of human action. Several authors have elucidated the gap between the level of analysis of research aimed at clarifying organizational level outcomes such as organizational culture (Krackhardt and Kilduff 1999, Kilduff and Krackhardt 2008) or research excellence (Rogers 2000). These authors suggest that although activities that determine both a culture and research excellence take place on the individual level, management scholars typically focus their attention on the organizational level. As pointed out by Kilduff and Krackhardt (2008), the organizational literature traditionally addresses organizational culture from a top-down perspective, from which organizational culture is viewed as being generated by mechanical solidarity, which emerges from shared norms in an organization and to which managers socialize new members of an organization. In reality, however, organizational culture is two-dimensional. Networks of friendship generate the second dimension of organizational culture. Two aspects of the networks are important: Friendship networks typically emerge around shared values (Lazarsfeld and Merton 1954), and in these networks, meanings are negotiated. As pointed out by Kilduff and Krackhardt (2008), different circles of friends may interpret the same norm or rule completely differently, or even oppositely. Therefore, the inherent ambivalence and uncertainty of knowledge production processes as well as the changing nature of science (i.e., increasing diversity, globalization, and accountability to the public) necessitates an understanding of friendship patterns. For example, as mentioned, I found that among U.S. scientists and engineers, it is U.S. native-born citizens, those with faculty spouses and partners, and more central and active individuals have more friends in their professional networks. However, when I examined the patterns of the prevalence of friendship by academic rank (not reported), I found that among assistant professors, non-white scientists and engineers have more friends than other groups.

While this finding requires further inquiry, it is illustrative of the greater diversity of younger cohorts of scientists in the United States as well as the changing color of “boys networks,” whether they are old or new. With respect to research excellence, friendship networks are most likely to be the locus of where the understanding of what constitutes excellence in science is negotiated (Krackhardt and Kilduff 1990, Polanyi 2000). According to Polanyi (2000), networks, a locus of scientific opinion, contains links, each of which establishes agreement about the valuation of scientific merit. The standards of scientific merit are institutionalized and passed on from generation to generation of individual scientists in the same ways as moral, legal, or artistic traditions. In fact, these friendship networks may be indicative of “whose” science it is (Harding 1991, Merton 1973[1972]). According to numerous observers, gender as well as race and class have all been reflected and sustained by science (Fox 2006, Ginther 2006, Merton 1973[1972] among others).

5.3. Limitations

As an exploratory study of the role of friendship in academic science, this study has made some useful contributions, as noted above. Yet, it also has some limitation.

A key limitation of the work is in the measurement of friendship itself. While the unique personal network data used for the testing of the hypothesized effects of friendship are appropriate for addressing the research questions of this study, the survey was designed to study career advancement. Thus, the name interpreter questions were designed to capture (a) productivity relevant factors, not (b) actual productivity. Productivity-relevant factors, such as the career advancement or satisfaction determine knowledge production context, which may facilitate or impede scientist’s knowledge production efforts. Productivity factors such as knowledge, time, or effort, in turn, are inputs in knowledge production.

The focal concept of this dissertation, friendship, was included in the survey as a measure of relational closeness. While respondents were asked if they considered named individuals being "close friends," the parenthetical explanation of the concept was not include, leaving it open to interpretation, which may vary across individuals and cultural backgrounds. Therefore, the interpretation and generalization of the findings should be regarded as primarily exploratory. Not only would a richer picture have been possible if the definition of friendship had been given and measured on a scale, but it would also have been a more reliable measurement of its quality. Nonetheless, the data were sufficient for addressing the core questions of this dissertation and revealed useful suggestions about the role of friendship in science.

A second key limitation is that this dissertation focused on the positive impact of friendship, which is consistent with the theoretical perspective of networked social capital, but did not consider detrimental effects. I have examined friendship as a strong tie that fosters cooperation. However, while strong ties foster a normative environment that facilitates cooperation, they may impede other productivity-relevant activities of scientists such as the search and location of novel information (Coleman 1988, Hansen 1999). Thus, while I find that friendship aids publication productivity, as measured by the publication count, it does not reveal how friendship affects the quality of the published work. An argument exists that strong ties may result in network constraints, be a source of redundant information, and lead to such negative consequences as group-think, collusion, and cognitive lock-in (Gargiulo and Benassi 2000, Granovetter 1973, Flache and Machy 1996, Janis 1982). While the context of science, this could potentially result in lower quality work, it is not necessarily the case. Hogg (1992) argued, however, that a distinction should be made between personal attraction, positive regard and solidarity, which originate from friendship, and solidarity, which originate from depersonalized social attraction and group identification. An experimental study that compared the roles of friendship and social attraction in groupthink found that it was group identification and social attraction, not friendship that were strongly and positively related to the symptoms of groupthink (Hogg and Hains 1998).

This dissertation has treated friendship as a positive and possibly catalytic influence on productivity. Nevertheless, while friendship is generally seen as a positive resource for the integration of social structures and the attainment of organizational goals, it may also have negative consequences on both individual and organizational levels. As noted elsewhere, the limited variance in the operationalization of friendship in this work does not allow for the examination of the nuances of friendship and the potential extent of effects (both positive and negative) on productivity and other professional outcomes. Further study may examine these additional dimensions and effects of friendship in science.

At the individual level, while positive effects were found here, negative consequences on the conduct of science may result from having friends in one's professional network. Social network theory addresses not only the advantages of strong ties but also their limitations. More specifically, while strong ties provide trust-based resources such as advice and tacit knowledge, too many strong ties within one's network (such as friendship) may also limit new information and increase redundancy. For example, a recent study of the productivity of biomedical research scientists found a negative and diminishing return of the number and the strength of collaborative relationships in knowledge creation (McFadyen and Canella 2004). One of the mechanisms by which networks of strong ties between similar individuals may impede goal attainment is the inefficiency generated by the lock in when a network of friends self-selects and then closes its "door" to others. In other words, networks of friends may be less open to new ideas or input, so they network risks becoming too close of a group to allow for innovation and discovery. While studies of friendship in various professional settings suggest that friendship-based ties allow for the discussion of risky and untested ideas (Gibbons 2004), it is uncertain whether this finding is generalizable to science, especially in the fields of high reputational competition, in which scientists try to establish their research agenda as the dominant one and their results as the key ones for future work (Bourdieu 1991, Whitley 2003).

At the organizational level, studies in professional settings have addressed the effects of workplace relationships on organizational dynamics. While workplace friendships have generally positive effects on work satisfaction, commitment, team climate, interpersonal exchange, and employees' decisions to stay with organizations (Morrison 2004, Song and Olshfski 2008, Tse et al. 2008), negative effects can occur when employees move. For example, if a close friend leaves the organization or team, the effect on a "stayer" may be traumatic and result in dissatisfaction or a negative attitude towards one's job or organization (Krackhardt 1985). This effect can be amplified when more than one friend or a closer friend leaves. In fact, it may induce all friends to leave the organization and move elsewhere. Given the mobility of academic scientists, this factor could be important in regard to work satisfaction and even organizational commitment for academic scientists who do not or who are not able to move.

Jones and Volpe (2011) have shown that the strength of individuals' organizational relationships facilitates their identification with that organization. Krackhardt and Kilduff (1990) argued that it is informal social structures such as friendship networks that facilitate the emergence and modification of that organization's culture. According to these authors, an understanding of friendship networks is important to securing support for organizational change. We might also believe that friendship networks also have a negative effect on diversity and integration across the status groups within that organization if they are formed exclusively within the perceived status groups. In the academic setting, this is potentially damaging because of the high costs associated with the attrition of talented women and U.S. citizen-scientists in the fields of science (Cozzens 2000, Etzkowitz et al. 2000, Stephan and Silvia 2008).

Finally, in the context of science, informal networks are sometimes seen as a mechanism for the perpetuation of undesirable (e.g., sexist) values (Farr 1988, Monroe et al. 2008). As communication systems, informal networks are criticized for being unstable, short lived, expensive to maintain, and resistant to institutionalization (Cronin 1982). Thus, future research should also be designed to capture any possible negative, or less desirable, effects of friendship in academic science.

5.4. Policy Implications

The policy implications of the findings of my dissertation primarily concern the enhancement of research competitiveness. The heart of research competitiveness is scientific excellence. The primary activity of achieving excellence is collaboration[9] taking place at the individual or team level, but the analysis of research competiveness has been conducted at the institutional level (Rogers 2000). The findings of my analysis emphasize the importance of individual level factors, namely personal collaborative communities (conceived as ego-centric networks) of academic scientists and engineers to their publication productivity, which may have implications for how grants and collaborative projects are managed and how institutions support collaborative work.

I have demonstrated that the relational properties of personal collaborative communities, that is, the properties of ties that constitute these communities, affect collaborative the publication productivity of academic scientists and engineers. Moreover, I have demonstrated that personal communities that span institutional boundaries are conducive to individual publication productivity. My findings emphasize the importance of dyadic collaborations.[10] As pointed out by creativity researchers (Sosa 2011), a productive pairing of collaborators is an important factor for fostering creative interactions and outcomes. In the context of academic science, scientists and engineers have relative autonomy in the selection of their collaborators (Bozeman and Corley 2005) in ways that maximize the potential for productive outcomes, and the maximization of these outcomes is in their best interests. Moreover, in academic science, personal collaboration networks can be seen as self-organized teams, some of which are interconnected and some connected only through the focal individual. Thus, flexible

[9] According to Rogers (2000) "the idea that collaborations are indicators of research competitiveness is consistent with the observation that cooperative activities are an inherent element of contemporary scientific research. What the two lessons together bring to the fore is that collaboration cannot be coherently construed as a strategy of the 'have-nots' to reduce the advantage of the 'haves.'"

[10] Ego-centric netoworks, may, in fact, be interpreted as a collection of dyadic relationships.

administrative arrangements that support the maintenance of distributed relationships might benefit scientists' productivity.

My findings also contribute to the discussion about the role and the integration of foreign-born scientists and engineers. U.S. universities are increasingly recruiting international faculty members to bring international expertise, enhance scientific innovation, and diversify university and campuses, all of which raise awareness of the global nature of research (Stephan 2010). As a result, U.S. universities are a diverse mix of native and foreign-born scholars (Stephan and Silvia 2008). Consistent with prior research (Corley and Sabharval 2007, Lee and Bozeman 2005, Mamiseishvili and Rosser 2010), I found that foreign-born U.S. scientists and engineers were more productive than their naturalized counterparts, and that foreign citizens have fewer friends and are more likely to have no friends among their closest collaborators, that is, within their immediate academic community. In light of recent research that documents that foreign born-scientists are more productive but less satisfied and lower paid than U.S.-born scientists (Corley and Sabharval 2007, Mamiseishvili and Rosser 2010), this finding emphasizes the importance of reconsidering policies aimed at these scientists. The findings of my dissertation suggest that personal relationships such as friendship are a potent and underutilized resource that could aid integration of the scientific community.

5.5. Conclusion

In the context of academic science, individual-level productivity is an outcome of a complex web of processes that start with an opportunity or opportunities and proceed through the creation of new knowledge and its dissemination. In these processes, scientists and engineers self-organize in personal collaborative networks in which professional aspects are intertwined with both social and personal aspects. Both of these aspects of collaborative networks are manifested in the role structure of the relationships that comprise these networks. While social aspects are manifested in such roles as advice-giving, personal aspects are manifested in close friendship ties. Friendship plays a distinct and important role of integrating these primary professional communities of academic scientists and engineers by mobilizing the social capital embedded in these personal professional networks and thus facilitating the pooling of all available resources in the pursuit of scientific knowledge. This role is highlighted in the observed significant positive effects of friendship on all of the resources mobilized from collaborative networks as well as in the impact of friendship between the closest of collaborators on their publication productivity. Overall, the results of this dissertation show that friendship, albeit not the most important social relationship is a factor relevant to the productivity of scientists and engineers.

APPENDIX

Tables of means for the estimation sample

Table 6-1 Prevalence of friendship: Estimation sample for Model 1

N=906	Mean	Std. Dev.	Min	Max
Dependent Variable: Friendship				
Has at least one friend	.61	.49	0	1
Number of friends	1.40	1.61	0	8
Seniority and accomplishments in the science community				
Career age	17.38	9.84	1	54
Number of offices in professional associations	.25	.54	0	3
Number of grant proposals	8.35	11.98	0	200
Demographic Characteristics and Context				
Female	.46	.50	0	1
U.S. naturalized citizen	.14	.35	0	1
Foreign citizen	.19	.39	0	1
Academic family background	.17	.37	0	1
Academic spouse	.27	.44	0	1
Department size	36	28	1	177
Chemistry	.22	.41	0	1
Computer science	.16	.37	0	1
Earth and atmospheric sciences	.24	.43	0	1
Electrical engineering	.16	.36	0	1

Table 6-2 Effects of friendship on resource mobilization: Estimation sample for Model 2

N=906	Mean	Std. Dev.	Min	Max
Dependent Variable				
Mobilized total of resources	9.14	5.80	0	31
Mobilized collaboration of journal paper or book chapter	2.51	2.12	0	10
Independent variable				
Number of friends	1.40	1.61	0	8
Other Independent Variables:				
Network properties				
Size of network	5.28	2.40	1	10
Demographic Characteristics and Context				
Female	.46	.50	0	1
U.S. naturalized citizen	.14	.35	0	1
Foreign citizen	.19	.39	0	1
Career age	17.38	9.84	1	54
Chemistry	.22	.41	0	1
Computer science	.16	.37	0	1
Earth and atmospheric sciences	.24	.43	0	1
Electrical engineering	.16	.36	0	1

Table 6-3 Effects of friendship for publication productivity: Estimation sample for Model 3

N=906	Mean	Std. Dev.	Min	Max
Dependent variable				
Count 2007-09	7.46	6.99	0	71
Fractional count 2007-09	2.20	2.03	0	18.57
Independent variable				
Number of friends	1.41	1.61	0	8
Number of friends with whom respondents were Ph.D. students together	.13	.40	0	3
Other Independent Variables:				
Network properties				
Network size	5.28	2.40	1	10
EI-Index	.03	.50	-1	1
Mobilized total of resources	9.14	5.80	0	31
• From friends	3.16	4.00	0	23
• From other ties	5.98	4.60	0	30
Mobilized collaboration on journal papers and book chapters	2.51	2.12	0	10
• From friends	.82	1.18	0	7
• From other ties	1.69	1.76	0	10
Resources				
Grant resources (# of graduate students)	2.26	2.52	0	20
Demographic Characteristics and Context				
Female	.46	.50	0	1
U.S. citizen (naturalized)	.14	.35	0	1
Foreign citizen	.19	.39	0	1
Career age	17.38	9.84	1	54
Chemistry	.22	.41	0	1
Computer science	.16	.37	0	1
Earth and atmospheric sciences	.24	.43	0	1
Electrical engineering	.16	.36	0	1

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